Agriculture's Role
in
Protecting Groundwater

CONSERVATION GEM PROGRAM MANUAL

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December 1991

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GROUNDWATER EDUCATION IN MICHIGAN

I. INTRODUCTION

Ground water is the water below the land surface that completely fills (saturates) the pore spaces in the subsurface materials. Ground water is a vital part of rural life. Nearly 95 percent of rural families in the United States rely on ground water as their source of drinking water. In addition, there are many agricultural uses for ground water such as irrigation and livestock watering. Also, it is a critical component of our natural resource base. The quality of life in the rural community depends on an abundant and dependable supply of potable ground water (i.e. suitable for drinking).

The ground water system is poorly understood by most people. Misconceptions are common. For instance, the perception of ground water occurring as underground lakes and streams is <u>not</u> accurate in most circumstances. Misconceptions like this stem largely from our inability to visualize the water held beneath the surface. Other misunderstandings, particularly those related to the effects of our surface activities on ground-water quality, often lead to unintentional serious threats to our ground water resources.

Anyone who has ever seen photographs of the earth taken from space can appreciate why some call our world the water planet. About 70 percent of its surface is covered by water. But more than 97 out of every 100 drops of water on earth are saline and, therefore, not potable (Table 1). The largest storehouses of fresh water on earth are the ice caps and glaciers. But they are not easily accessible sources of drinking water. Ground water is the premier source of readily available fresh water for human consumption. Compared to other fresh water sources, ground water is 25 times more abundant than all the lakes, reservoirs and rivers of the world combined!

The current quality of our ground water resources is generally very good in most locales. In many rural areas it is used and consumed with little or no treatment. Ground water quality is at risk though. Many common urban, industrial, and farm practices are a potential threat to the quality of our ground water .

Given the economic and life-sustaining importance of ground water to rural residents, we must collectively ensure the conservation of its quality and quantity through education and prudent land practices. An appreciation of the benefits of ground water, coupled with an understanding of the basic concepts of water movement throughout the farm environment, will help us realize the link between our actions at the land surface and how they affect our ground water resources.

Table 1. Estimated Distribution of the World's Water Supply

Total saline waters	97.2079 %	
Oceans	97.2	
Saline lakes	0.0079	
Total fresh waters	2.7921	% of total fresh water
Ice caps and glaciers	2.158	77.289
Ground water*	0.61	21.847
Lakes and reservoirs	0.015	0.537
Soil moisture	0.008	0.287
Atmosphere	0.001	0.036
Rivers	0.0001	0.004

* to a depth of 13,000 feet

[modified from Heath, 1987 and Fetter, 1988]

II. BASIC HYDROLOGY & GROUND WATER FLOW

Introduction

Hydrology is the study of the movement and interaction of water on the earth surface, below the surface and in the surrounding atmosphere. Surface water includes streams, rivers, ponds, lakes and the oceans. Water below the ground surface that occupies the tiny open spaces within the soil and subsurface materials is called **subsurface water.** Subsurface water has two components, one is soil moisture which is found in unsaturated areas and the second is ground water which is found in the saturated areas. The water in the atmosphere is held as water vapor which may condense as droplets to fall as precipitation. These three areas of water storage are dynamically linked to each other by the continuous movement of water from place to place. This is the concept of the **hydrologic cycle** (Figure 1).

The Hydrologic Cycle

Within the hydrologic cycle, water moves into and out of the three storage areas (surface water, subsurface water, and atmospheric water). The input of water to one area must be accompanied by an output from another. The pathways of water movement within the hydrologic cycle are outlined in Table 2.

Energy

The driving force behind all water moving pathways are the energy differences from point to point throughout the hydrologic cycle. Solar energy is the primary driving force for the water movement pathway between the surface and the atmosphere. As an example, Figure 2 shows vapor being added to the atmosphere by the evaporation of pond water. Water will always move from a point of higher energy toward the point of lower energy along the path of least resistance. Water will move, for instance, from a zone of higher pressure to one of lower pressure, from higher temperature to lower and from a higher elevation to a lower one.

Hydrologic Cycle

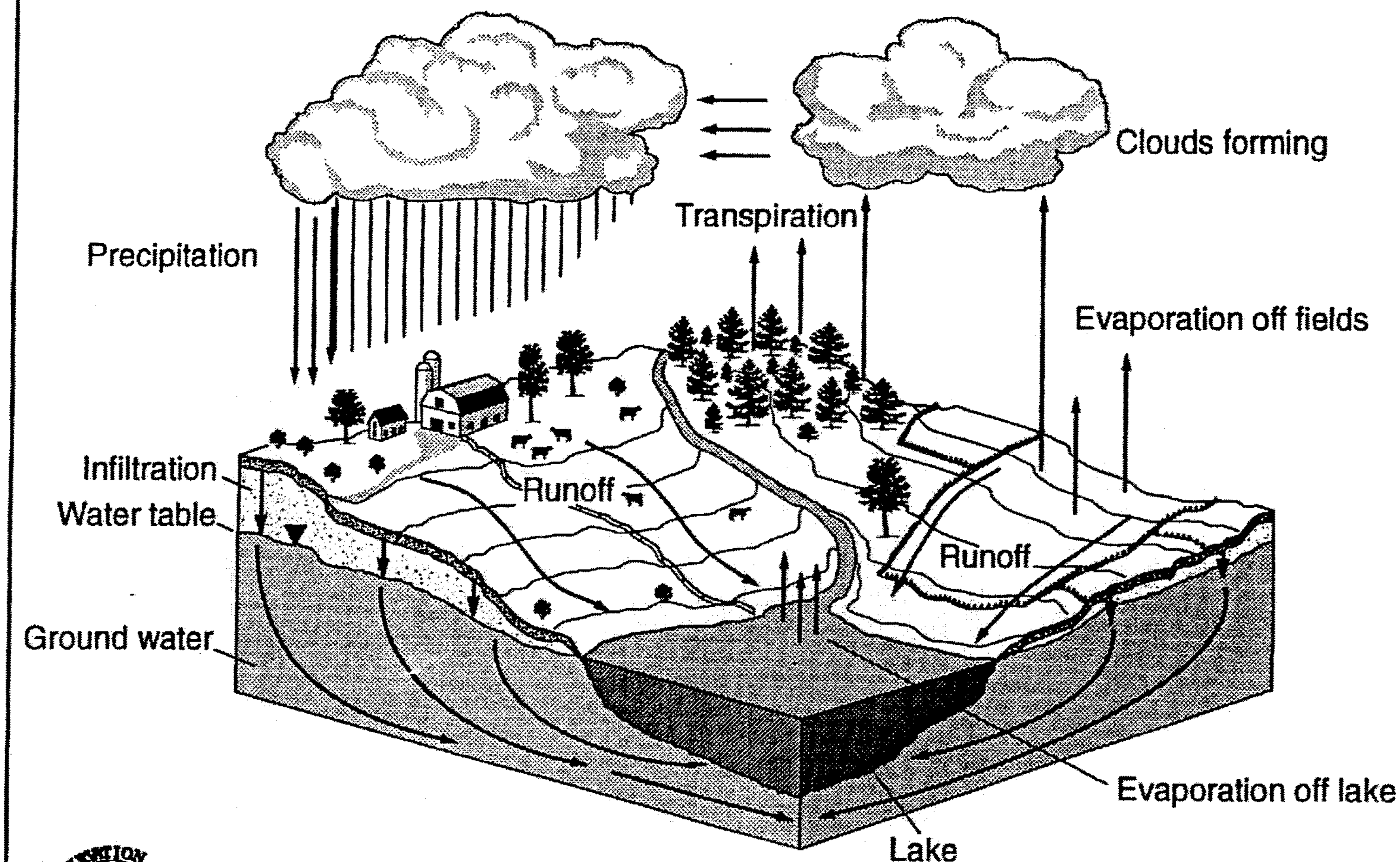

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Figure - 1

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Table 2. Mechanisms of Water Movement in the Hydrologic Cycle

* Atmosphere to Surface
    - precipitation (condensed water vapor)
        [rain, snow, hail, dew, frost]

* Surface to Atmosphere
    - evaporation from land or water surfaces
    - plant transpiration

* Surface to Surface
    - down slope stream flow
    - down slope overland flow

* Surface to Ground Water
    - ground-surface infiltration and downward movement
    - infiltration and downward water movement from loosing streams or ponds

* Ground Water to Surface
    - upward ground-water movement into gaining streams or ponds
    - root uptake
    - artesian water movement producing a flow at the surface from a confined aquifer release point

* Ground Water to Ground Water
    - down slope ground water flow within and between aquifers

Energy Sources for Water Movement

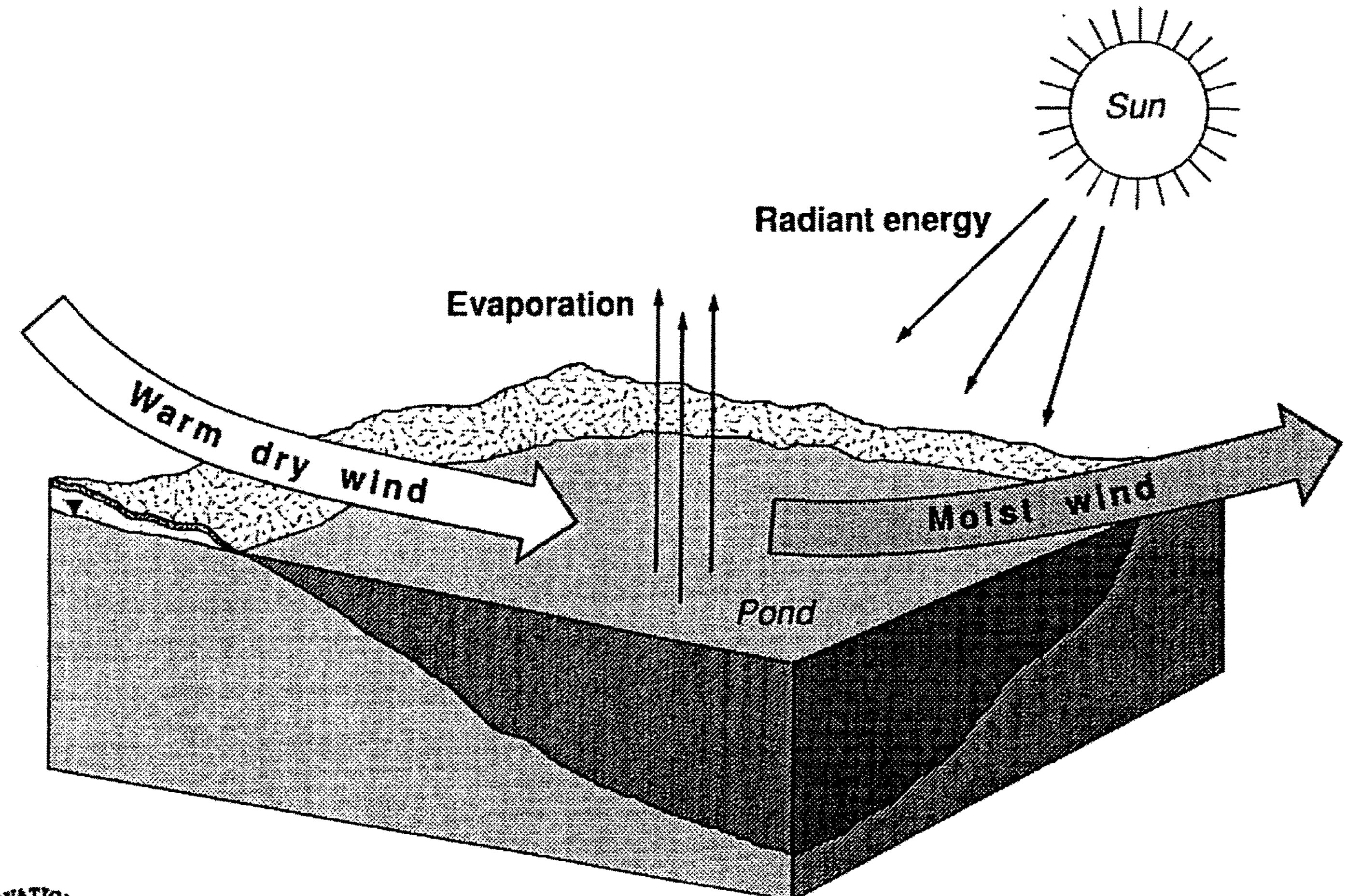

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Figure - 2

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The Farm-scale Hydrologic System

Introduction

For the hydrologic discussions throughout this manual the size of land area to be considered will be the farm site and the immediate vicinity around it. This will be considered the **farm-scale hydrologic system.** We will discuss water movement in terms of inputs and outputs through the different areas of water storage in the hydrologic system.

Water Pathways

The farm-scale hydrologic cycle is a description of the cyclical movement of water on and around the farm. Water travels through the cycle by various pathways (Figure 3). The time to completely travel through the hydrologic cycle can vary greatly. Beginning as a raindrop, water can move vertically downward through the soil surface and unsaturated areas as soil moisture and further into saturated areas as ground water. Ground water moves very slowly through the subsurface material. It can creep along, almost horizontally, on a slight grade for years and possibly centuries until it reaches a distant discharge site (Figure 4). On the distant surface, the water can evaporate and finally fall as precipitation again. A much shorter cycle would be precipitation falling onto the ground surface and immediately evaporating. That water could, but usually doesn't, return as precipitation in a few hours.

Water Inputs

Inputs to the farm-scale hydrologic system include all precipitation and irrigation. Rain, dew, snow, sleet, and hail are all forms of precipitation. Irrigation water is applied to the farm-scale hydrologic system from above surface, at the surface and by subsurface methods.

Water Outputs

Outputs from the farm-scale hydrologic system include water movement by surface flow, evaporation from soil and plant surfaces, and infiltration into the subsurface. Surface flow occurs as runoff from snow melt, excess rains or over-irrigation. **Evapotranspiration** is a combination of two water movement pathways, evaporation and transpiration.

Water Pathways

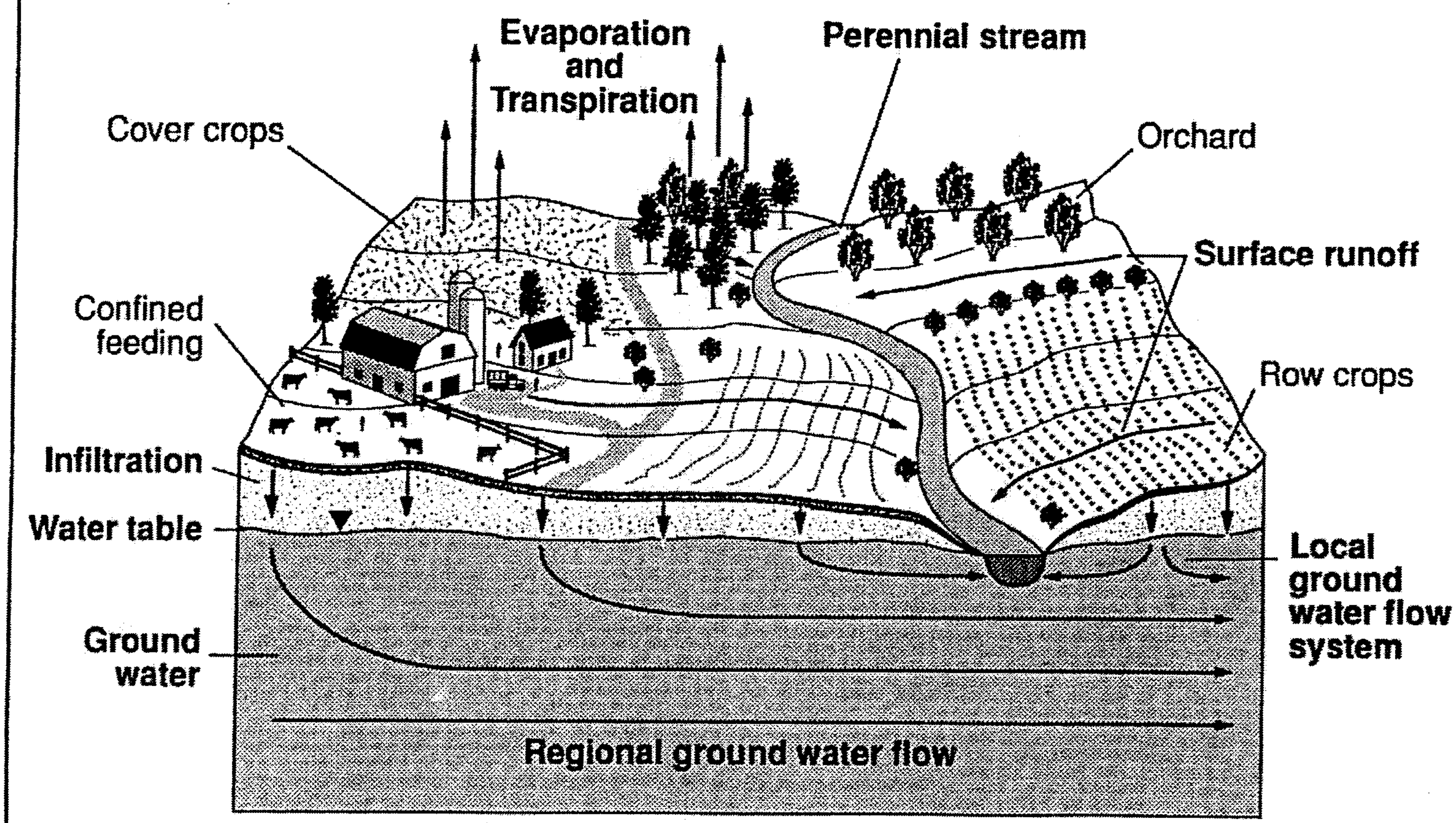

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Figure - 3

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Hydrologic Time Scales

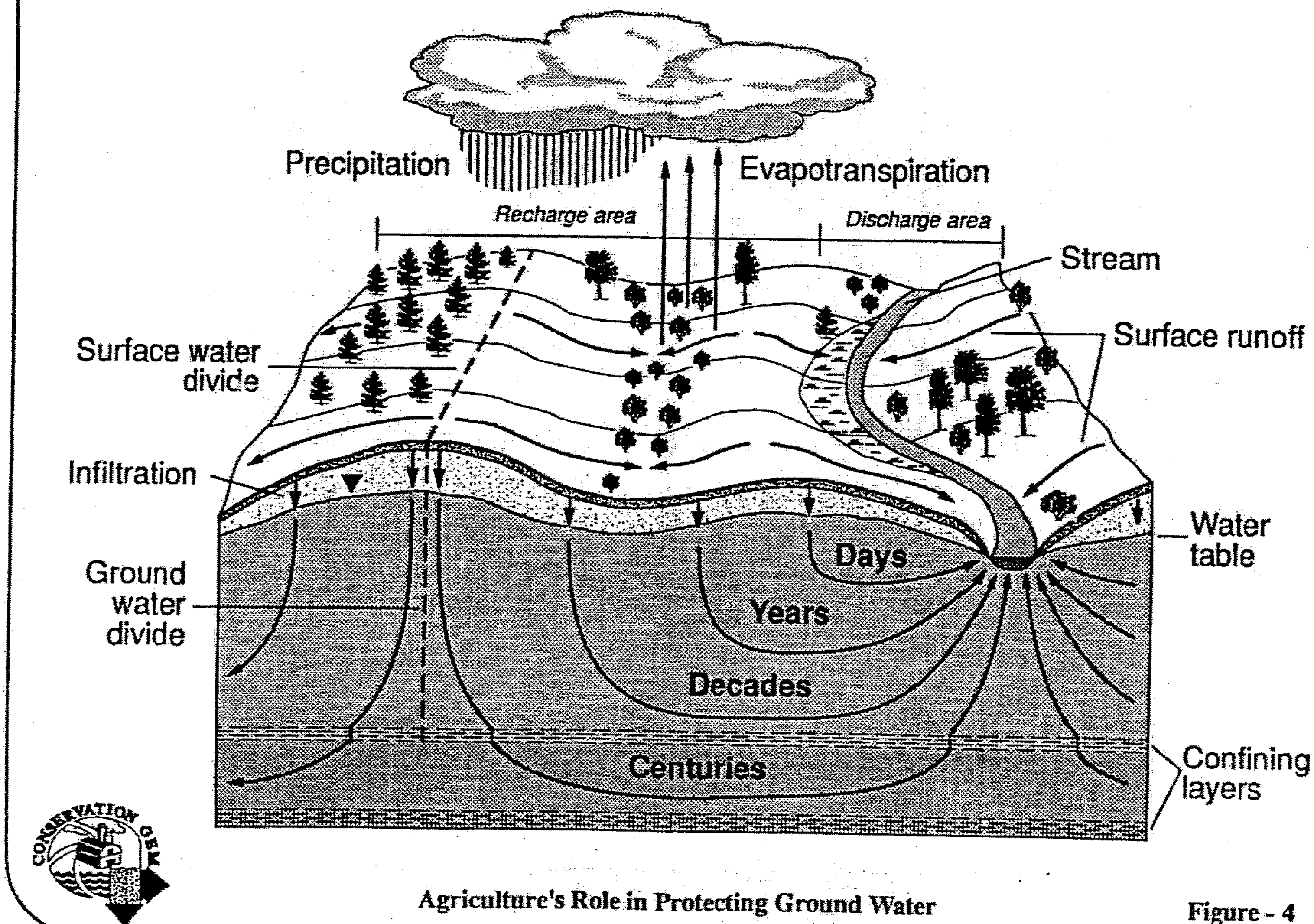

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Figure - 4

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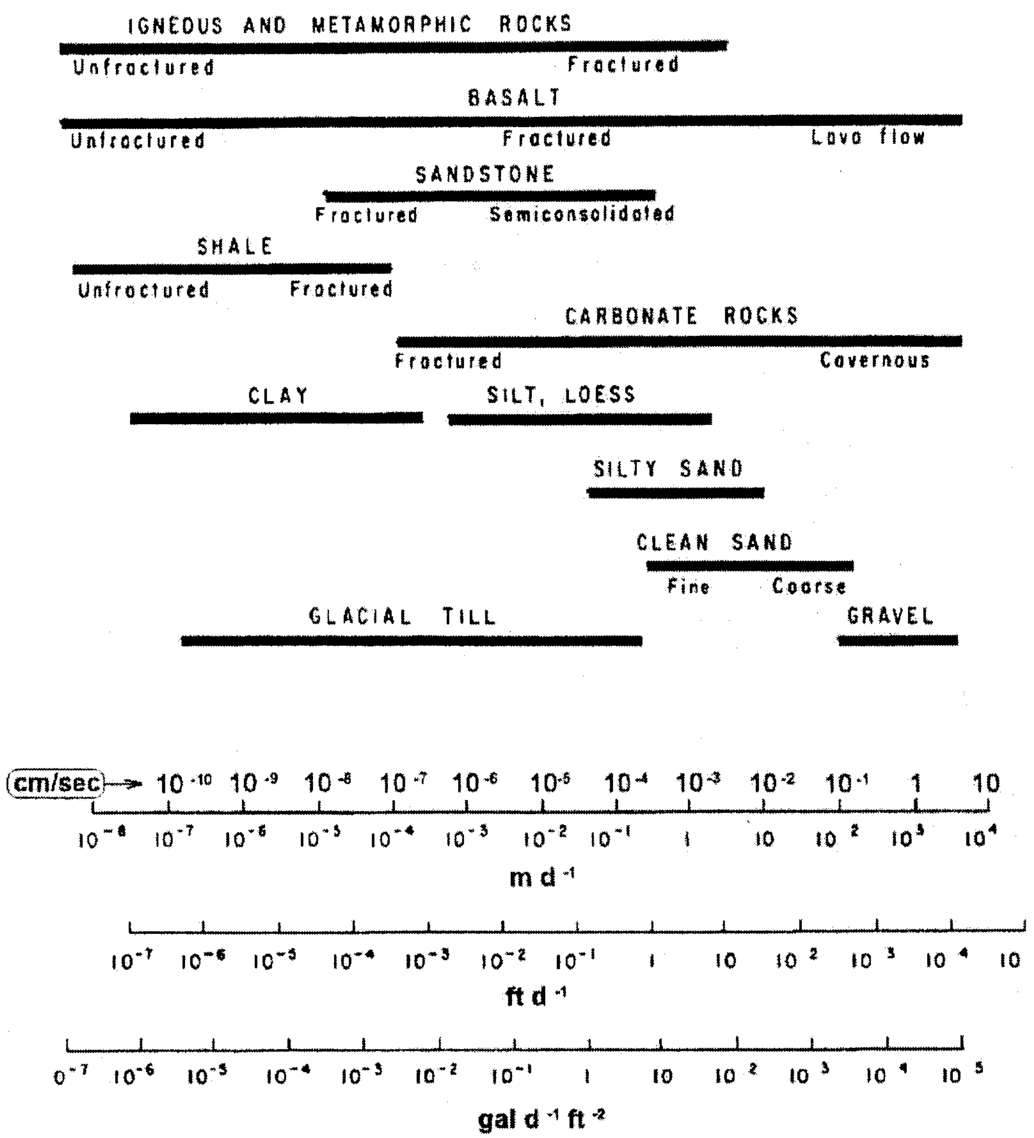
Hydraulic Conductivity of Selected Geologic Materials



Prepared by **David P. Lusch, PhD * Center For Remote Sensing * Michigan State University**

Evaporation is a change of liquid water, from land and water surfaces, to water vapor by energy from the sun and wind. Transpiration is the release of water vapor by plants through their leaves. **Infiltration** is the seepage of water into the ground and **percolation** is the subsequent downward movement of the water, through cracks and pore spaces, into the subsurface.

An additional output is subsurface drainage systems such as tile fields which move water from the subsurface directly to a ditch. Ground water may eventually flow out of the saturated zone directly into a surface water feature such as a stream. This input to perennial streams is called **base flow**. Thus the hydrologic cycle links ground water to surface water, and back again.

The Subsurface

Introduction

We have discussed the major components of the entire farm-scale hydrologic system. Now let's focus on the components of the subsurface and the water movement through this portion of the hydrologic system. The subsurface is divided into two principle regions, the unsaturated zone and the saturated zone (Figure 5). The subsurface materials in these areas can be characterized by their degree of compaction and cementation. From this viewpoint, geologic materials can be classified as 1) unconsolidated, 2) unconsolidated but totally compacted, or 3) consolidated, if compaction and cementation has occurred.

Unsaturated Zone

The **unsaturated zone** is the area of the subsurface that has a combination of air and water within its pore spaces. It contains the **root zone** which is the soil area that plant roots occupy in order to obtain water and nutrients. The unsaturated zone extends from the ground surface down to the **water table** which divides the unsaturated zone from the saturated zone. In other words, the upper surface of the saturated zone is the water table.

The amount of water held in the unsaturated zone is based on the amount of water that soaks into the surface, the amount absorbed by plant roots and the amount that moves downward across the water table into the saturated zone. The unsaturated zone holds water much like a sponge. It can vary from being nearly saturated, with all the soil pores filled, to being wrung out of excess water but still moist. Gravity is responsible for draining the excess water from the unsaturated zone. When the unsaturated zone reaches the point at which no more water can be pulled from it by gravity it is at its **field**

Subsurface Hydrologic Zones

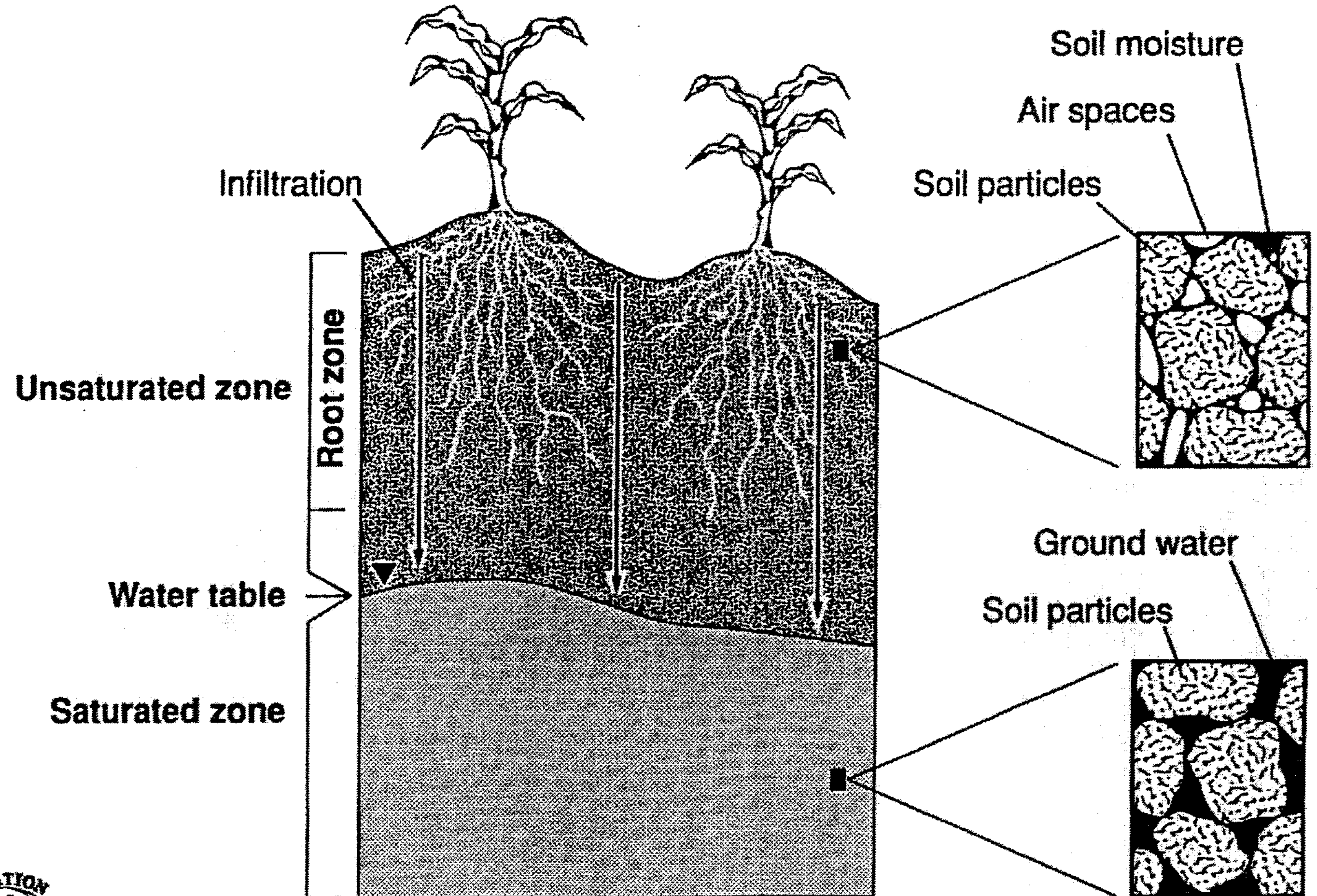


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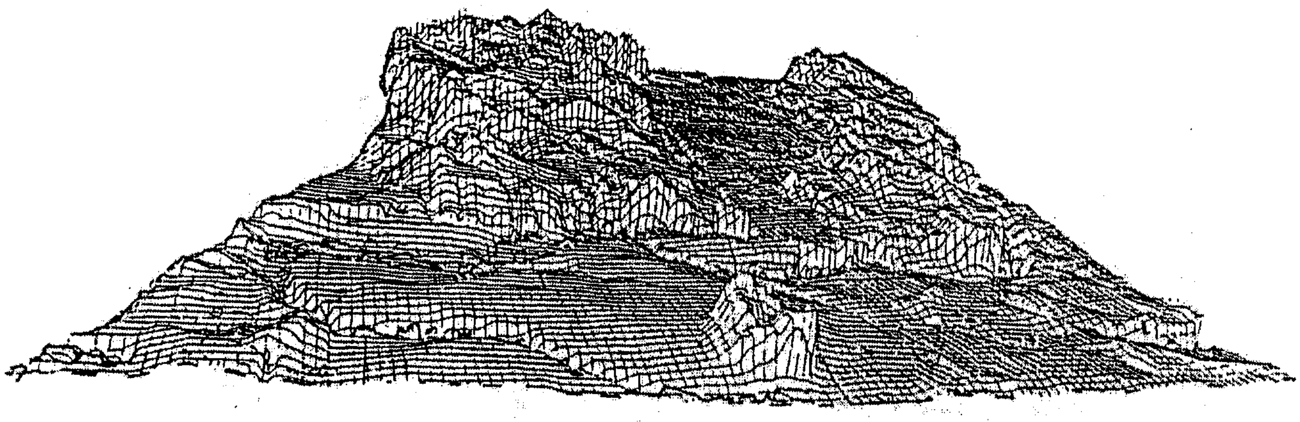
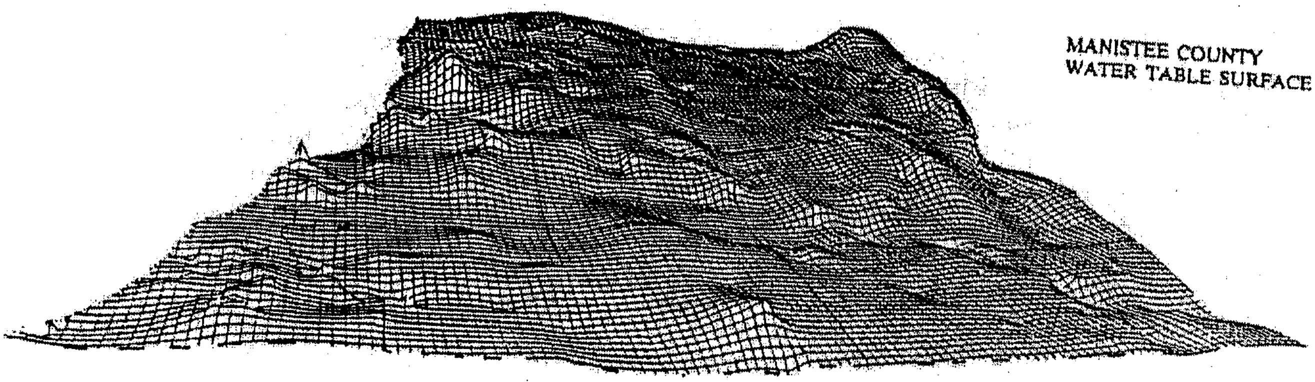
Figure - 5

MANISTEE COUNTY
LAND SURFACE





MANISTEE COUNTY
WATER TABLE SURFACE

capacity. Before water can infiltrate out of the unsaturated zone into the saturated zone, the water storage capacity (i.e. field capacity) of the soil must be exceeded. This fact provides the irrigation manager with a useful tool to keep expensive water and nutrients in the root zone rather than flushing them through to the water table.

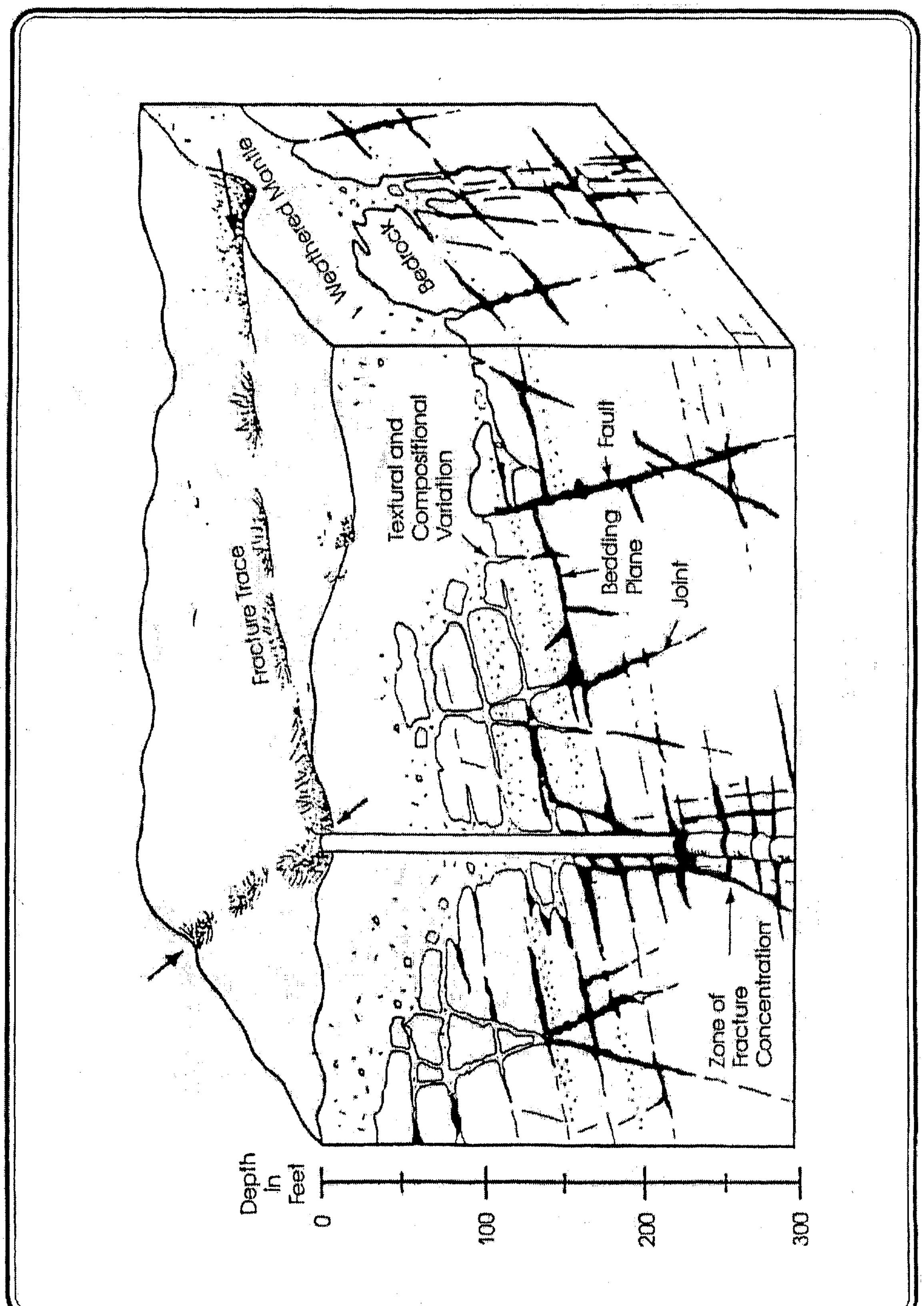
Saturated Zone

The **saturated zone** is the subsurface region where all available voids and pore spaces are completely saturated (i.e. filled) with ground water. This subterranean region can consist of multiple layers composed of soil materials (e.g. clay, sand, or gravel) or various types of consolidated rock. The layers within this zone that can supply ground water of an acceptable quantity and quality are called **aquifers**. Some layers can transmit a great deal of water and some very little, depending on the type of material it is composed of. Sandstone, for instance, can transmit more water than shale and a gravel aquifer can supply water more readily than one of clay material.

Water in the saturated zone, like all other areas of the hydrologic cycle, is moving. It moves much more slowly than water in the other parts of the cycle, but the reason for its movement is the same: an energy difference from higher to lower elevation. Stream flow velocities range from a few feet per minute to a many feet per second. In comparison, ground water moves very slowly. In a coarse sand aquifer, ground-water flow velocities may be as fast as 1 foot per day. A clay layer, on the other hand, may allow ground-water flow at a rate of only 0.3 inches per year!

Unconfined Aquifers

The saturated zone can have two types of productive aquifers within it, unconfined aquifers and confined aquifers (Figure 6). The **unconfined aquifer** is the region which is directly beneath the unsaturated zone with no barrier zones between them. Unconfined aquifers always remain at atmospheric pressure. The water table is the top surface of the unconfined aquifer. The height of the water table will vary with water subtractions from well pumping and water additions from excess infiltration that percolates down through the unsaturated zone and into the aquifer or saturated zone. Unconfined aquifers have a bottom barrier zone that slows downward movement of water and allows the water to build up into the unsaturated zone. With no barrier zone on top of the unconfined aquifer, the vertical movement of the water table from inputs and outputs occurs continually and with no pressure change.



Weathered Mantle
Bedrock
Fracture Trace
Textural and
Compositional
Variation
Fault
Bedding
Plane
Joint
Zone of
Fracture
Concentration
Depth
In
Feet
0
100
200
300

Aquifer Types

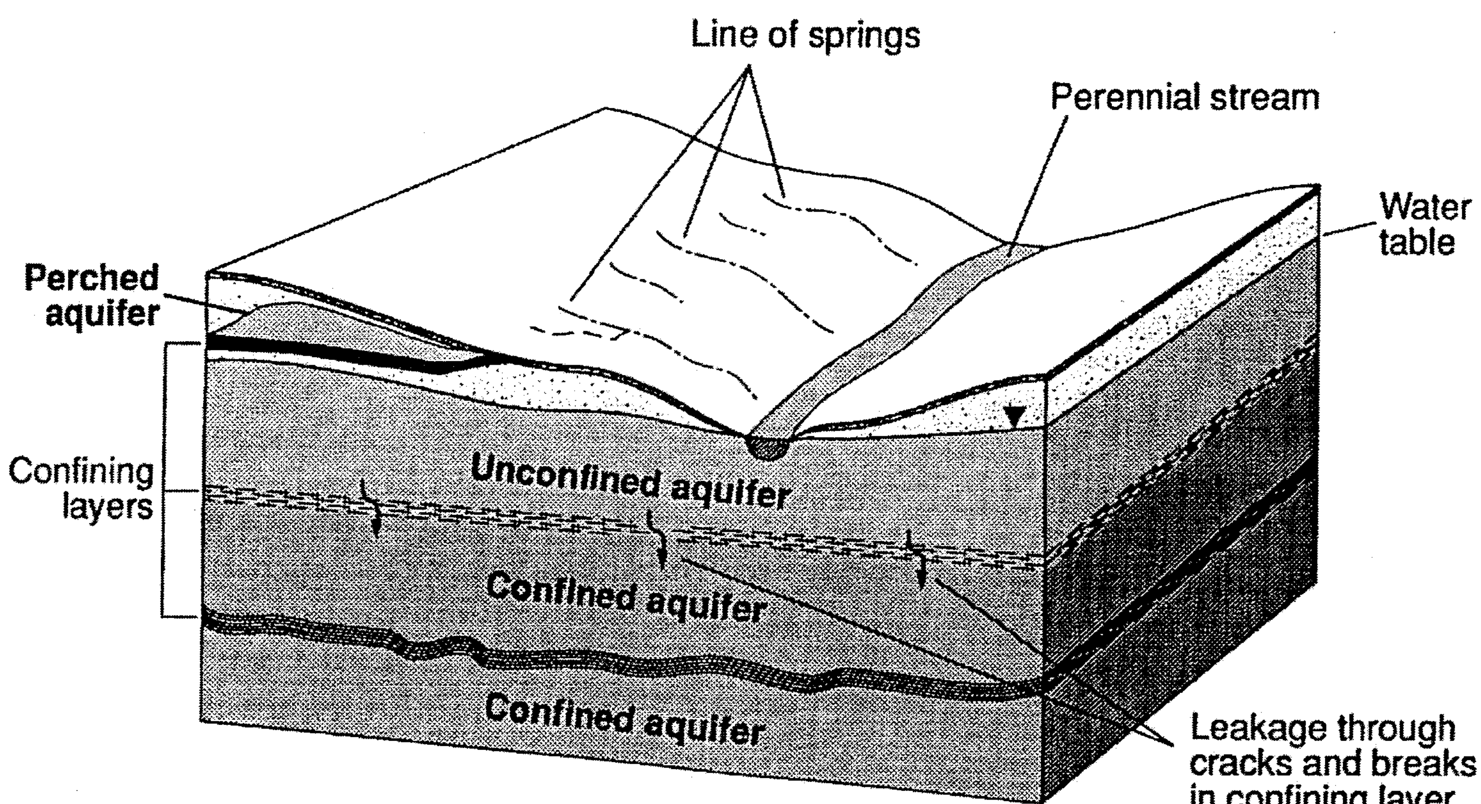


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Figure - 6

Confined Aquifers

Confined aquifers are bounded above and below by barrier zones called confining layers. These **confining layers** are geologic materials which slow or restrict the movement of ground water relative to the adjacent aquifer. Water pressure in a confined aquifer is always greater than the atmospheric pressure. This is because in a confined aquifer the pressure is equal to the sum of atmospheric pressure plus the pressure exerted on the aquifer by the overlying confining layers. As a result, water levels in wells tapping confined aquifers always rise above the top of the aquifer (although not necessarily above the ground surface). These are called artesian wells. Confined aquifers are found below the unconfined aquifer. An aquifer zone can have more than one confined aquifer in it, but only one unconfined aquifer as shown in Figure 6.

Perched Aquifers

Figure 6 also shows **perched aquifers.** These are areas above the water table that can collect a small amount of water over a barrier zone of small areal extent. They generally are not productive sources for drinking water wells.

Aquifer Recharge

Aquifer recharge is the addition of water by percolation to the saturated zone from either the unsaturated zone or directly from surface water. This addition will cause the water table to rise as discussed above. Several aquifers may overlay each other, each with different directions of flow and different sources of recharge. Unconfined aquifers can be replenished over and over after water outputs (pumping, drainage and base flow), by recharge inputs from the surface and from saturated layers below. Confined aquifers are more difficult to replenish because of the confining layers on the top and bottom. Defining the location of aquifer recharge areas may be very difficult if the subsurface geology is highly variable. Subsurface heterogeneity is common in glaciated landscapes such as Michigan and the Great Lakes Basin.

Ground Water Flow

Ground water flow can occur over very large distances. Large aquifers can underlie areas as extensive as 100,000 square miles. In Michigan, the largest regional aquifer is less than one-third this size. The direction of ground water flow may be determined by measuring the elevation of the water surface within a group of wells. The water elevation in each of at least three wells must be known in order to determine the local flow direction. From these data, contours of equal water surface height can be drawn. The local flow direction is straight down this surface, at right angles to the water-height contours (Figure 7). Determining the direction of ground water flow can help in the resolution of existing pollution problems and aid in identifying vulnerable areas within a region.

Wells

Introduction

A **well** is a column drilled down through the subsurface to the saturated zone. Wells are used as water sources and as monitoring stations for determining the direction of ground water movement. Wells can be set into unconsolidated layers of material, like sand or gravel. These require a **well screen** to exclude the small, loosely packed materials around the well. A well screen is a slotted column beneath the well casing that blocks soil particles from traveling with the water through the pump (Figure 8). Wells drilled into completely consolidated bedrock have no need for a well screen. Typically, well depths in Michigan range from 15 to 500 feet, but most residential wells are less than 200 feet deep.

Aquifer Response To Wells

Confined aquifers and unconfined aquifers respond differently to wells. Water in a well penetrating an unconfined aquifer (Figure 9, Well "a") will rise to an elevation equal to the water table level which is at atmospheric pressure. Correspondingly, water in a well penetrating a confined aquifer (Figure 9, Well "b") will rise above the aquifer to an equilibrium elevation which is proportional to the pressure within the confined aquifer.

Ground Water Flow Direction

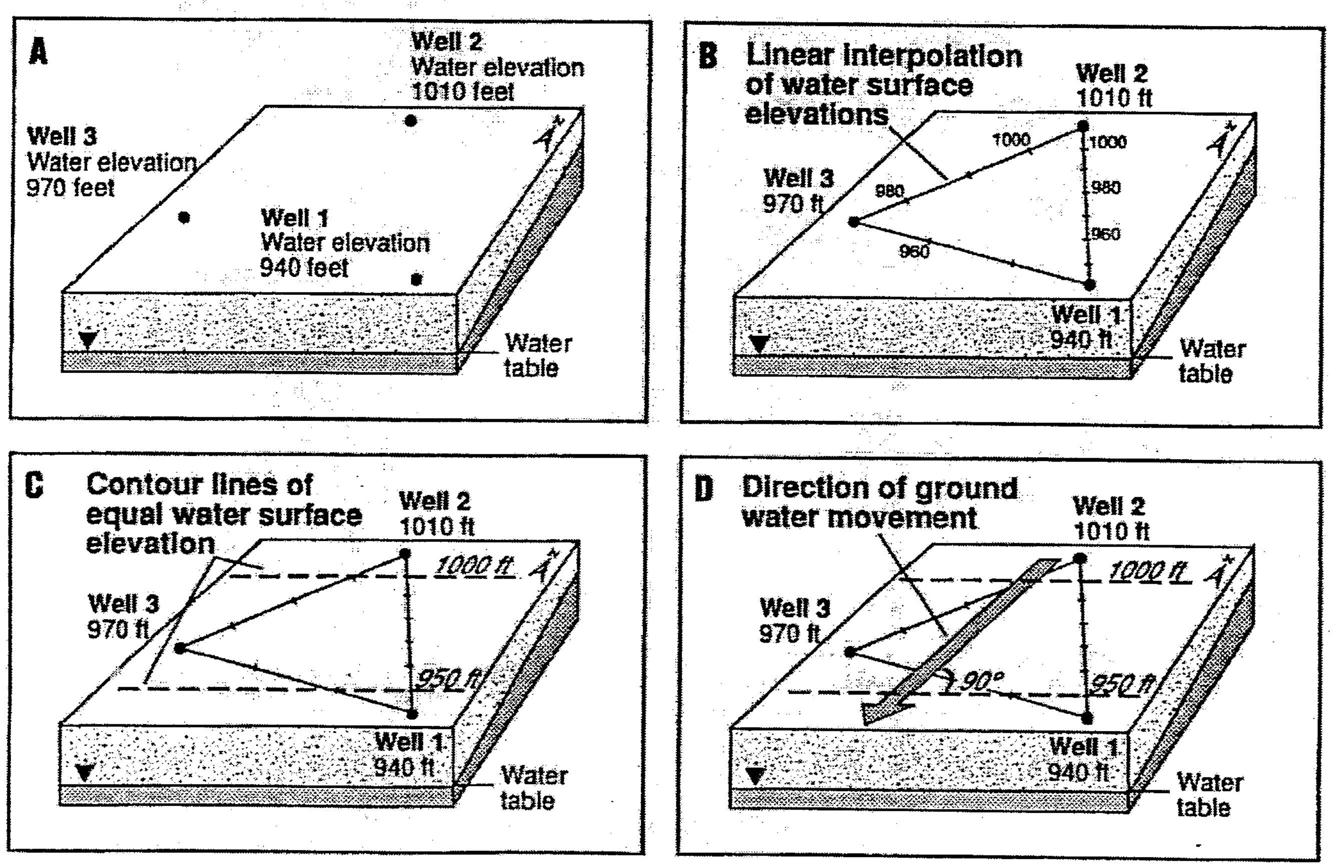

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Figure - 7

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Water Well Design

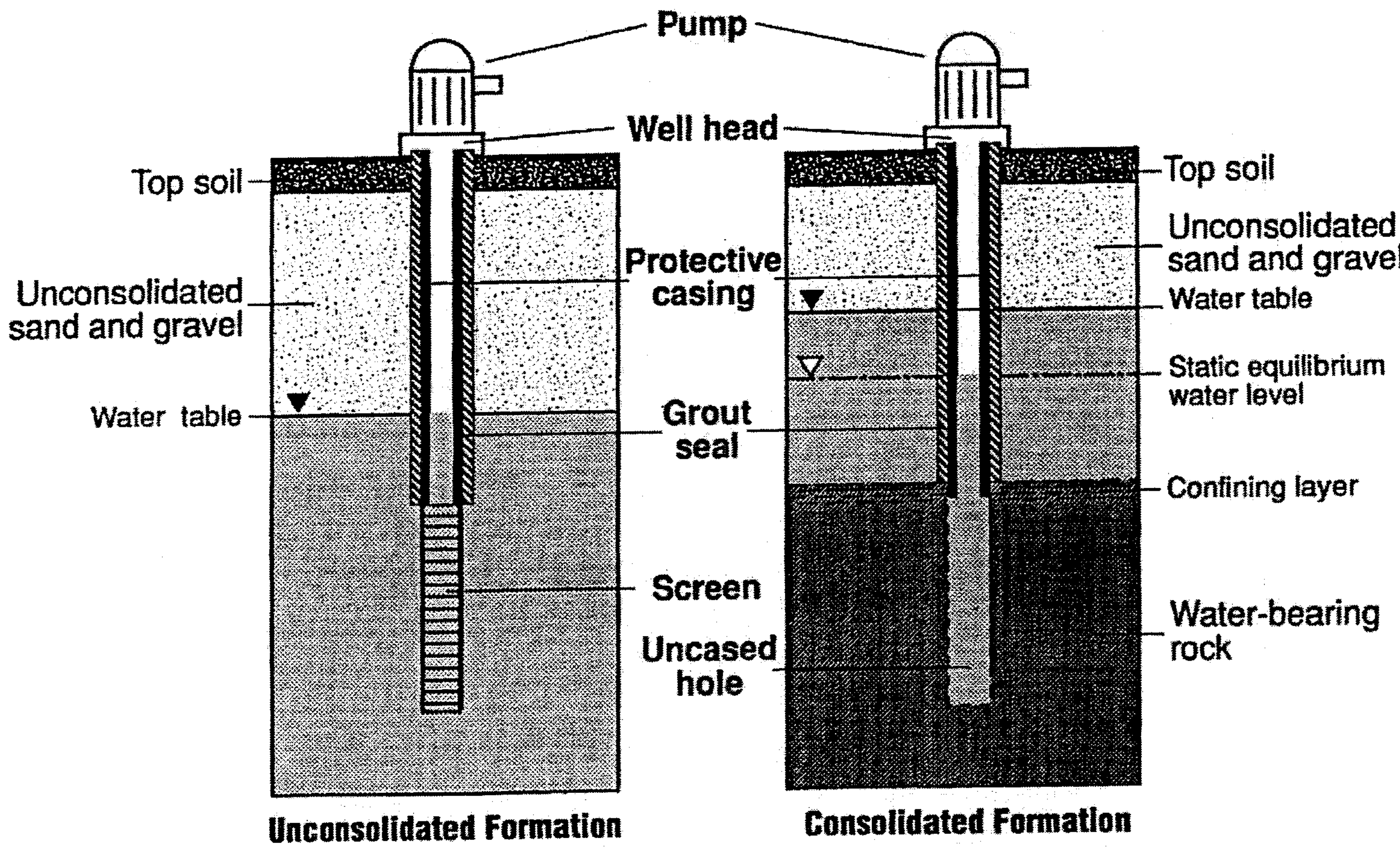

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Figure - 8

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Wells in the Saturated Zone

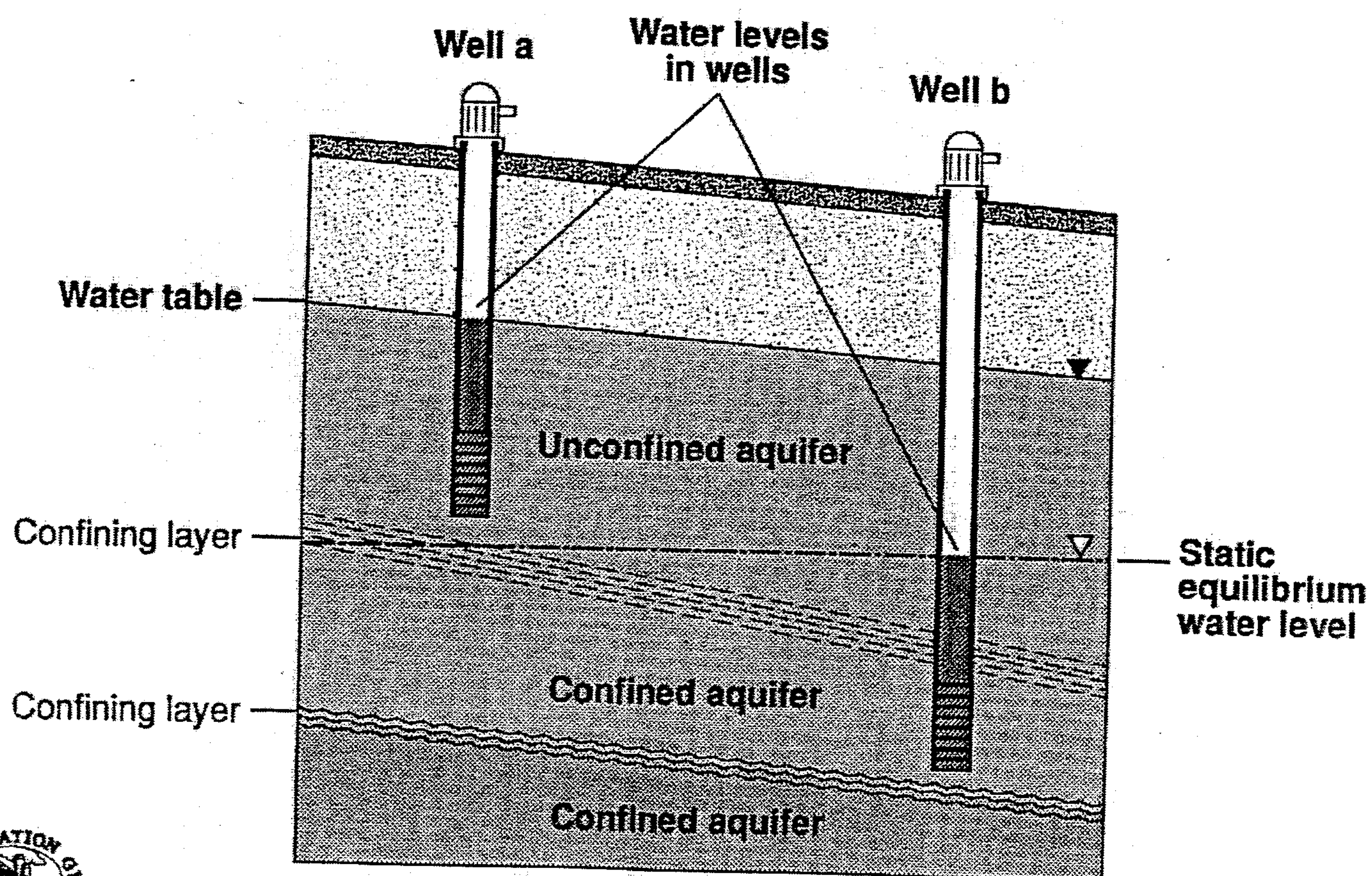

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Figure - 9

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Unconfined Aquifer Pumping

During pumping of an unconfined aquifer, the water table will be drawn down forming a **cone of depression** around the well column (Figure 10). The water removed from an unconfined aquifer comes not only from the movement of water through the saturated zone, but also from the dewatering of part of this zone, the compressibility of the aquifer material, and the expansion of the water upon pressure release. Above the sloping surface of the water table within the cone of depression, the soil material is no longer saturated with ground water. Below the sloping surface of the water table, ground water moves toward the well until eventually it enters the well screen and is lifted out. When pumping stops, the cone of depression fills with water from below as the aquifer returns to its equilibrium level (the water table). The drawdown around the well, established during pumping, causes an elevation difference which initiates water movement toward the well from surrounding areas. Increasing the pumping rate can enlarge and deepen the cone of depression. For a given set of aquifer characteristics, there is a pumping rate at which equilibrium is reached and the depth of dewatering stabilizes.

Confined Aquifer Pumping

In a confined aquifer, no cone of depression develops within the aquifer as a result of pumping. Pumping can, however, reduce the level to which water will rise in a neighboring unpumped well. Ground water will move toward the pumped well from outside areas, but the entire confined aquifer remains saturated (Figure 11). The water removed from a confined aquifer is accounted for by the expansion of the water upon pressure release and the compressibility of the aquifer material. Water removal from confined aquifers results in compaction of the aquifer material. Unconsolidated materials (e.g. sand & gravel) are subject to more compaction than consolidated materials (i.e. bedrock) because the cemented rock layers usually have a greater inherent strength.

Having completed our discussion of the farm-scale hydrologic cycle, and specifically subsurface water movement, we will now examine the effect of human activities on ground water within the farm-scale hydrologic cycle. We will look at how chemicals enter into and move within the farm-scale hydrologic cycle.

Pumping an Unconfined Aquifer

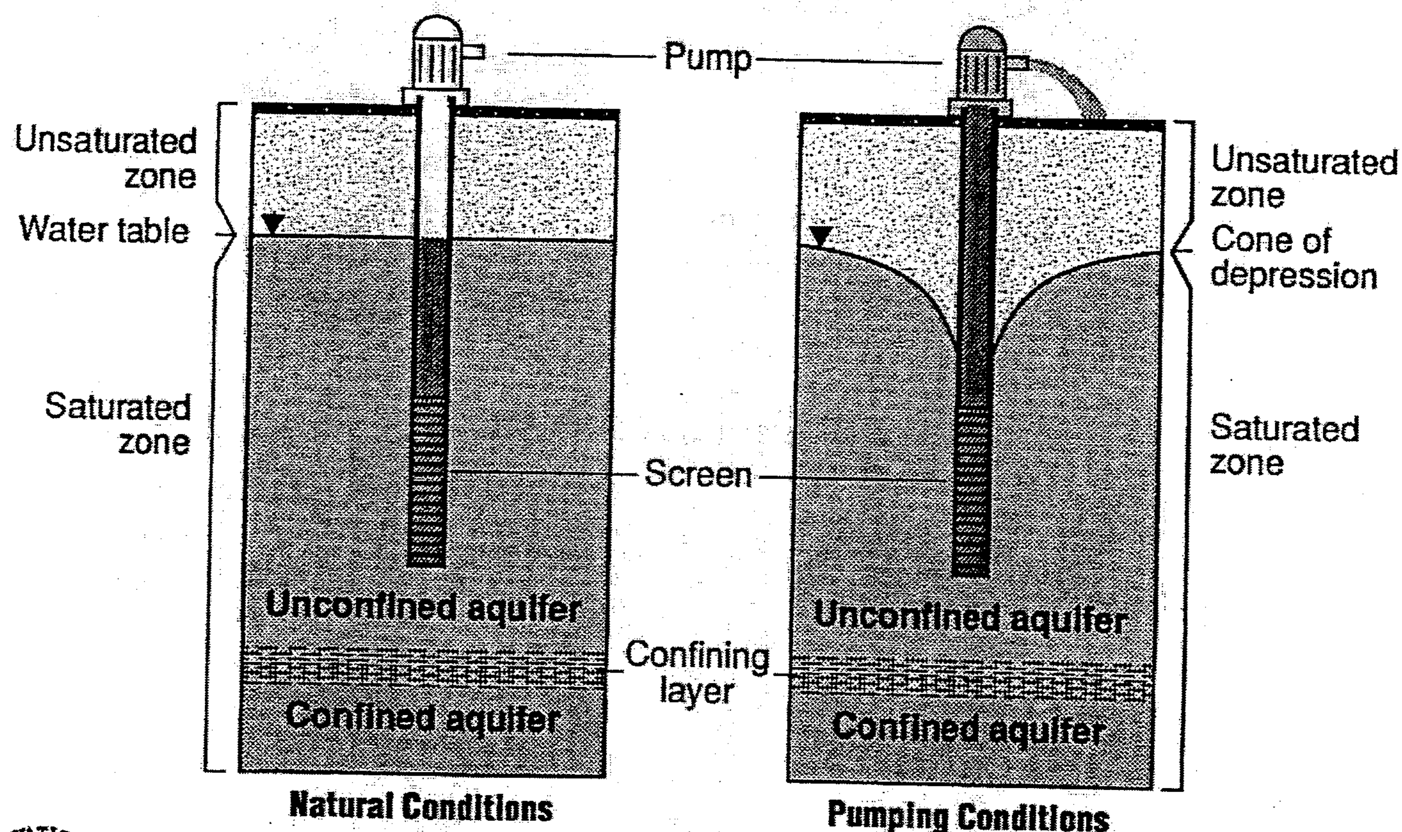

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Figure - 10

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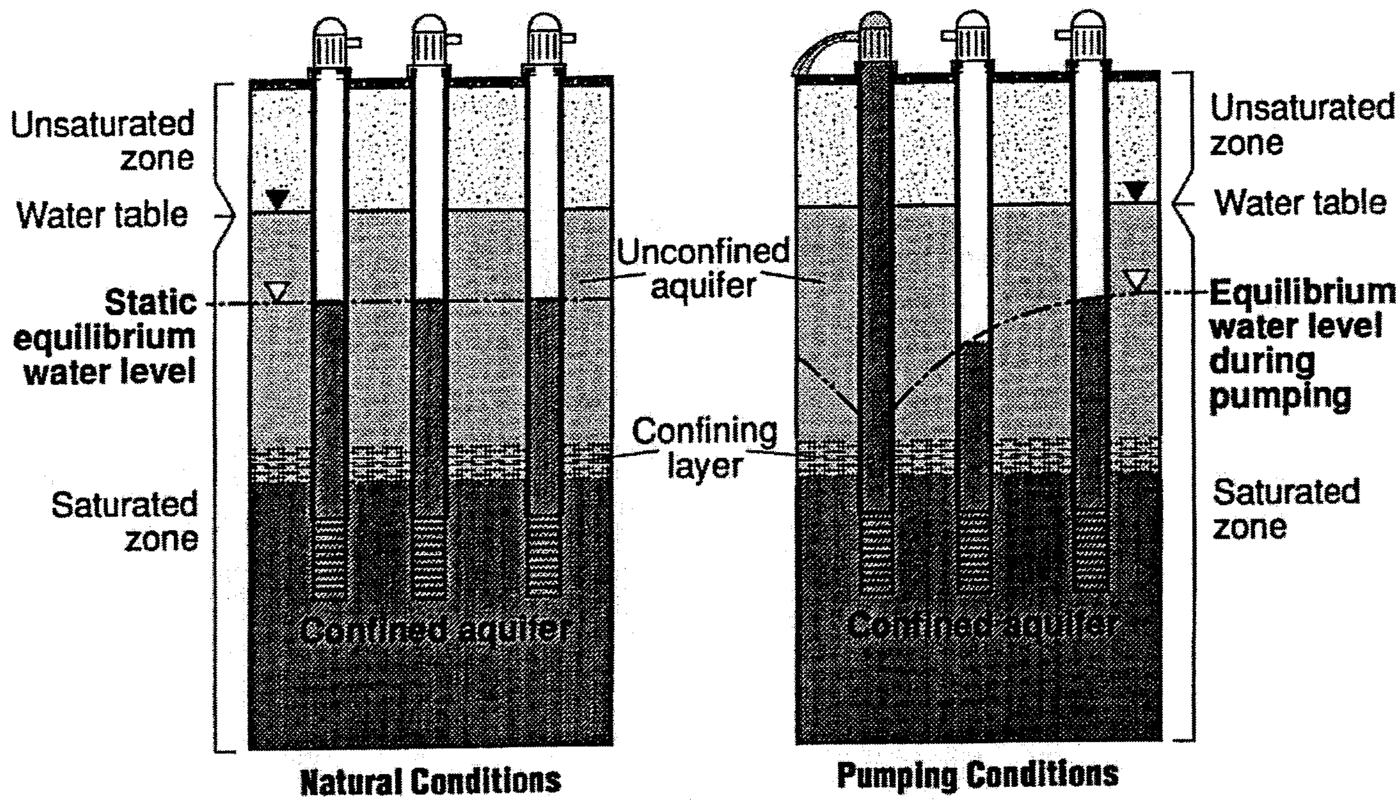
Pumping a Confined Aquifer



Agriculture's Role in Protecting Ground Water

Figure - 11

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Bedrock Geology

Structure

North America, like all of the Earth's continents, is composed of three components: a shield, a stable platform, and folded mountain belts. The core of the continent is the craton which encompasses both the shield and the stable platform. The Canadian Shield is an area of highly deformed, metamorphic rocks and granitic intrusions of Precambrian age (see Table 5) which are exposed in the region between Hudson Bay and the upper Great Lakes. These are some of the oldest rocks in North America. To the south and southeast of the Superior province of the Canadian Shield, including all of Michigan, the igneous and metamorphic rocks of the basement complex change in composition and are progressively younger, although still Precambrian, in age. Beginning in the eastern Upper Peninsula and continuing southward, the basement complex is covered with a sequence of Paleozoic and younger sedimentary rocks. Although originally deposited nearly horizontally, in the Central Lowlands region these lithified sediments have been warped into broad, shallow domes and basins.

In the Great Lakes Region, there are several broad uplifts where Precambrian basement rocks occur at or near the surface (Figure 18). To the south of Michigan, there is the generally north-trending Cincinnati arch. Midway between the Ohio River and southernmost Michigan, this arch splits into two prongs along the Indiana-Ohio border. The northeastward trend, called the Findlay arch, continues through the western end of Lake Erie to eventually join the Canadian Shield in Ontario. The other prong of the Cincinnati arch, commonly known as the Kankakee arch, trends northwestward to join the north-trending Wisconsin arch in south-central Wisconsin. The Wisconsin arch merges with the Wisconsin dome which occupies the majority of the northern third of Wisconsin. The western half of the Upper Peninsula continues this positive trend in the form of the Superior Upland, an extension of the Canadian Shield.

Table 5. Geologic Time Scale.

millions of years before present	duration in millions of years	EPOCH	PERIOD	ERA
1.6	1.6	Pleistocene	Quaternary	Cenozoic
5.3	3.7	Pliocene	Tertiary	
23.7	18.4	Miocene		
36.6	12.9	Oligocene		
57.8	21.2	Eocene		
66.4	8.6	Paleocene		
144	78		Cretaceous	Mesozoic
208	64		Jurassic	
245	37		Triassic	
286	41		Permian	Paleozoic
320	34		Pennsylvanian	
360	40		Mississippian	
408	48		Devonian	
438	30		Silurian	
505	67		Ordovician	
570	65		Cambrian	
				Precambrian
4,600 ?	Formation of the Earth			

Major Basement Rock Structures

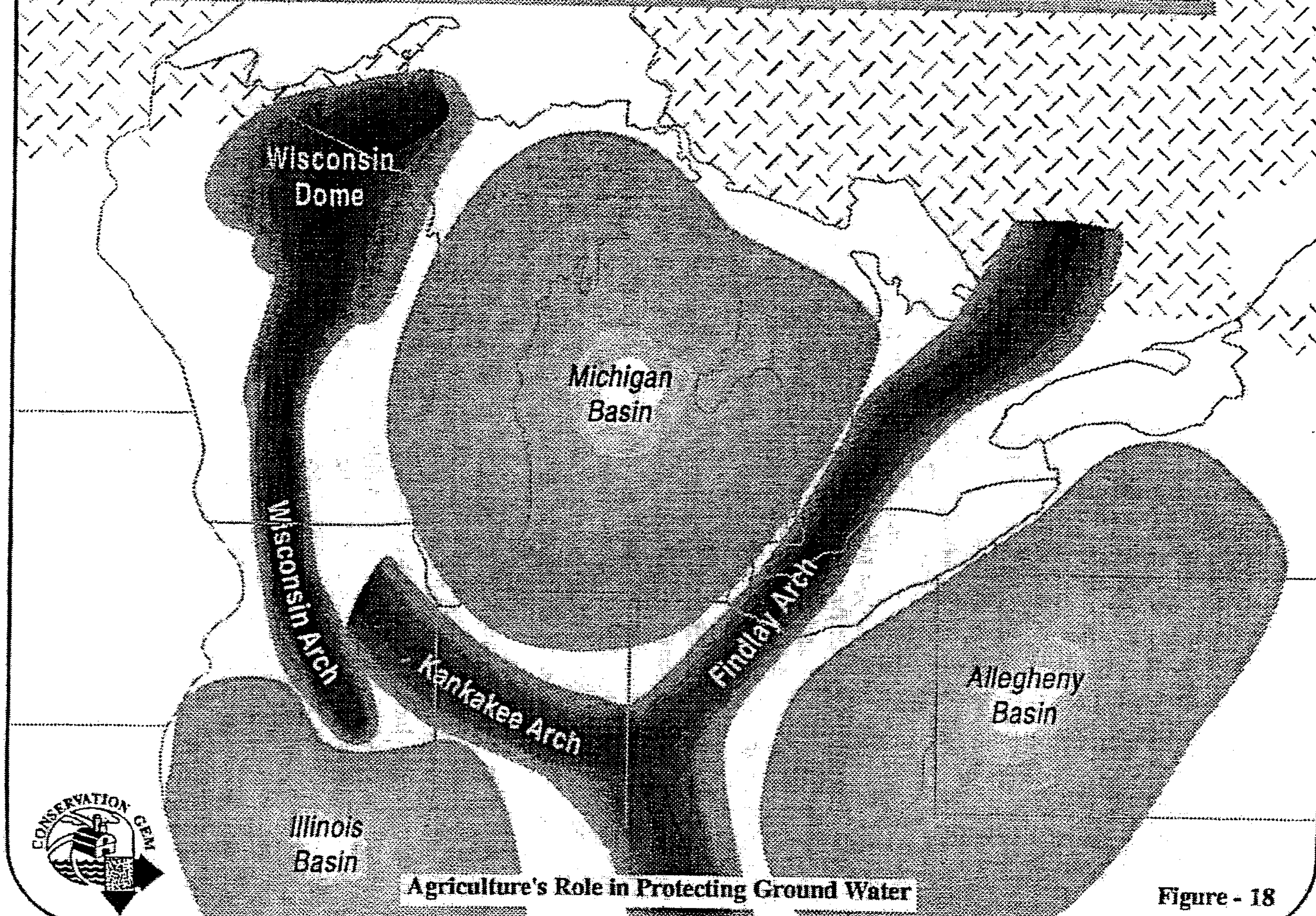

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Figure - 18

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The Michigan Basin is the central negative structure in the Great Lakes Region. It is bounded on the north by the Canadian Shield, on the east by the Algonquin arch, on the south by the Kankakee and Findlay prongs, and on the west by the Wisconsin arch/dome and the Superior Upland. Two other structural basins also occur in this region of the continent. East of the Findlay arch is the Allegheny Basin. The Illinois Basin lies southwest of the Kankakee arch.

The Michigan Basin encompasses about 122,000 square miles and contains about 108,000 cubic miles of sedimentary rocks which filled a depression in the Precambrian basement complex. The vast majority of these sedimentary rocks are Paleozoic age although patches of late Jurassic rocks subcrop beneath the glacial drift in the west-central portion of the Lower Peninsula (Figure 19). The oldest sedimentary rock unit in Michigan is the Jacobsville Sandstone of late Precambrian age which is found along much of the north shore of the Upper Peninsula (Figure 20). The oldest Paleozoic sedimentary rocks (Cambrian) are found at or near the surface along the northern fringe of the eastern Upper Peninsula and arcing southward to the big bend in the Menominee River in southern Menominee County. The oldest sedimentary rocks in the Lower Peninsula, found in southeastern Monroe County, are Silurian in age.

The thickness of the sedimentary rocks increases from the margins toward the center of the basin which is located near the middle of the Lower Peninsula. A hydrocarbon exploration well drilled in North Star Township, Gratiot County penetrated more than two miles of sedimentary materials before entering the Precambrian basement complex. The concentric, ovoid pattern of the sedimentary rocks in Michigan, illustrated in Figure 19, is an indication of the basin's saucer-like structure.

An example of the margin of the sedimentary basin is shown in Figure 20. The Ordovician and Cambrian units of the sedimentary sequence can be seen to thin as they reach the erosional limits of the basin. The underlying Precambrian rocks which slope down into the basin can also be observed in this cross section. Figure 21 presents a section across the Lower Peninsula which passes near the center of the structural basin. The inclinations of the various sedimentary units on this graphic have been greatly exaggerated for clarity. Basin-wide, the average dip of the beds is less than one degree -- about 45-60 feet per mile. Such a declivity would appear to be horizontal if viewed in an outcrop. Given the size of the basin, however, this slight inclination is sufficient to account for the rocks that form the coastline of the eastern Upper Peninsula being found over 10,000 feet below the surface of the central portion of the Lower Peninsula.

Bedrock Geology of Michigan

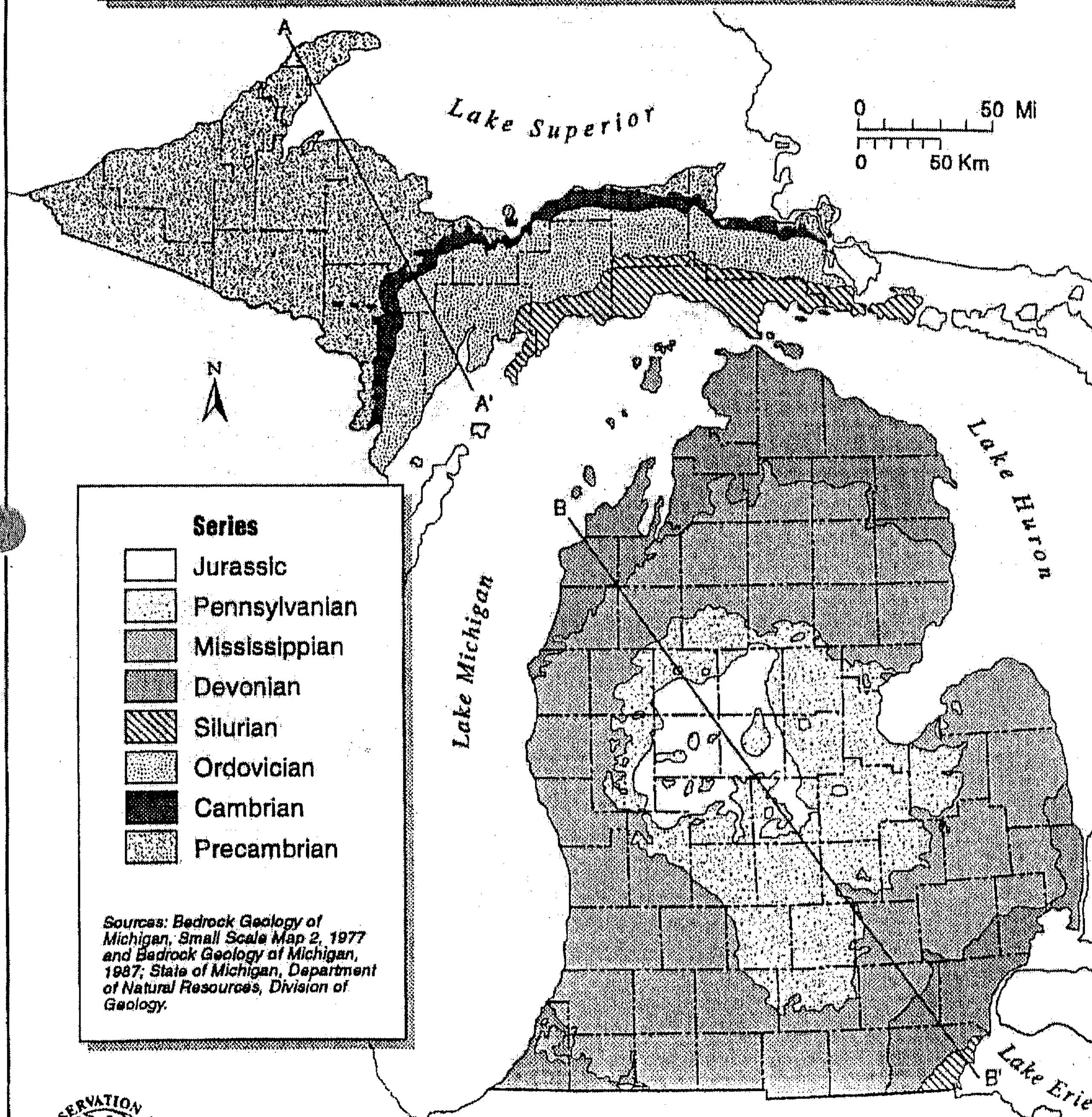

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Figure - 19

Geologic Cross Section of the Upper Peninsula

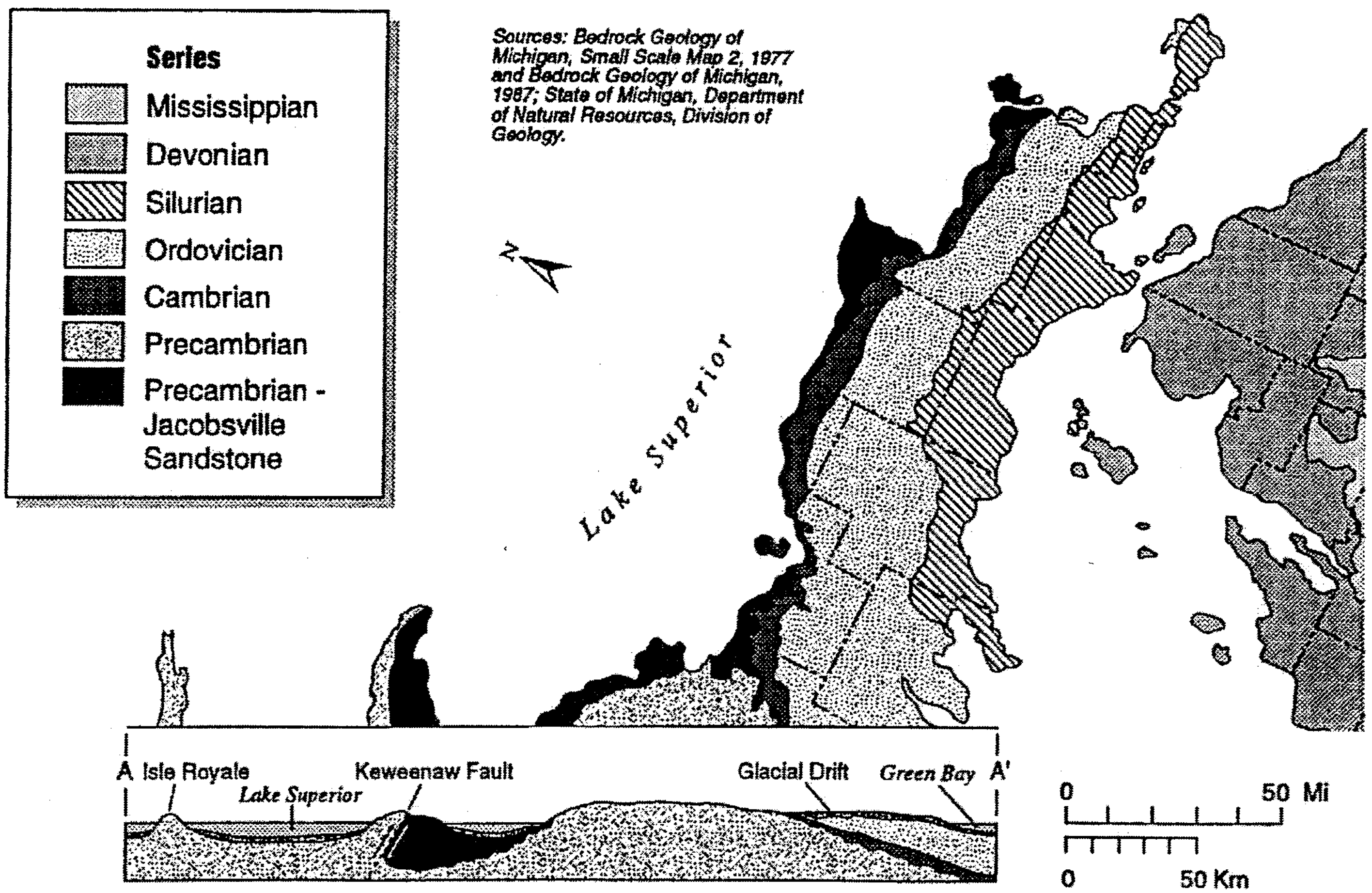

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Figure - 20

Geologic Cross Section of the Lower Peninsula

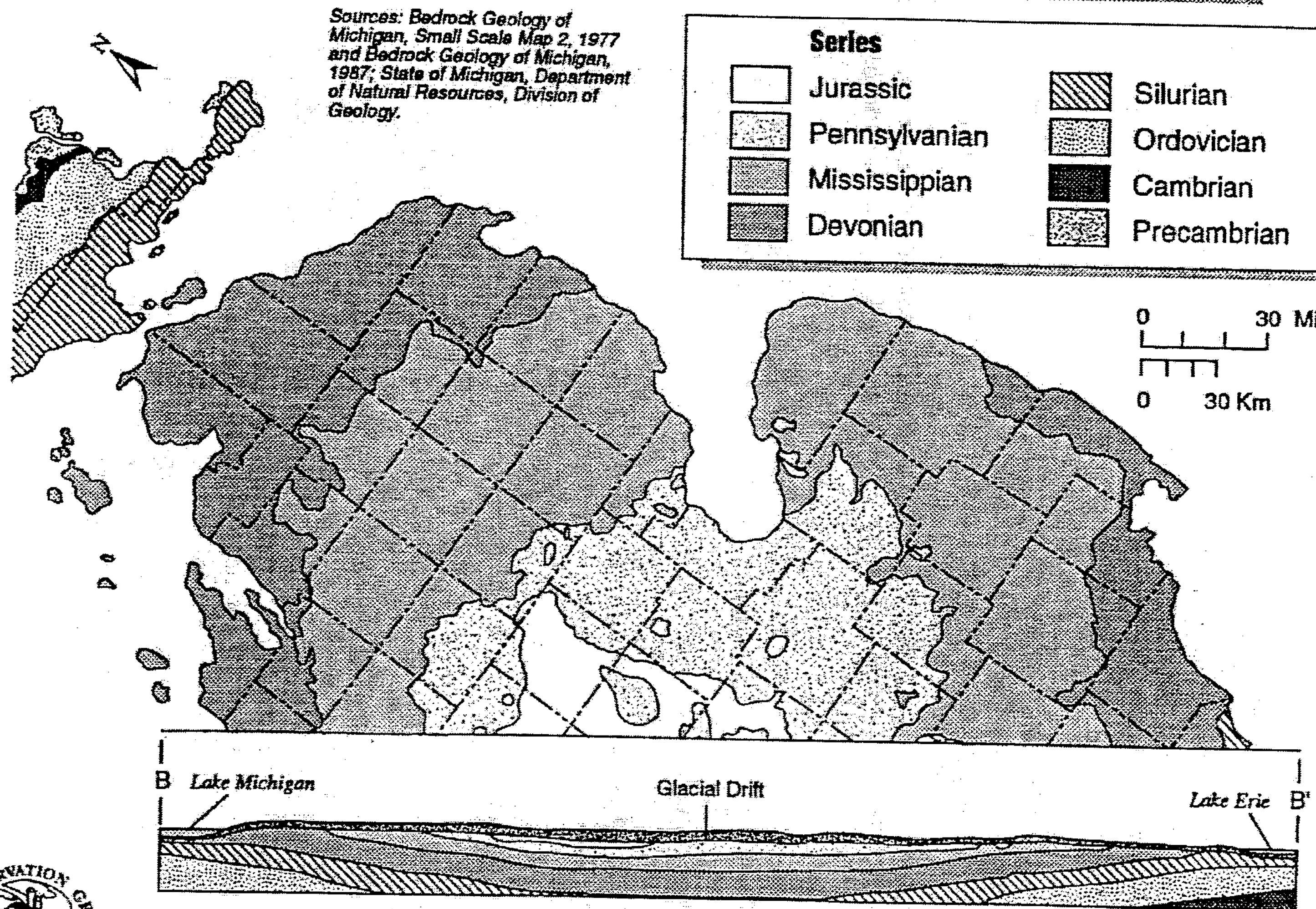

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Figure - 21

Lithology

As mentioned previously, the majority of the Precambrian basement complex is composed of crystalline rocks (i.e. igneous and metamorphic). An exception to this is the Precambrian Jacobsville sandstone, shown in part in Figure 20. Of the Paleozoic and Jurassic sedimentary rocks which fill the basin, about 47 percent of them are carbonates (i.e. limestone or dolostone), 23 percent are sandstones, 18 percent are shales, and roughly 12 percent are evaporites (i.e. salt, anhydrite, and gypsum).

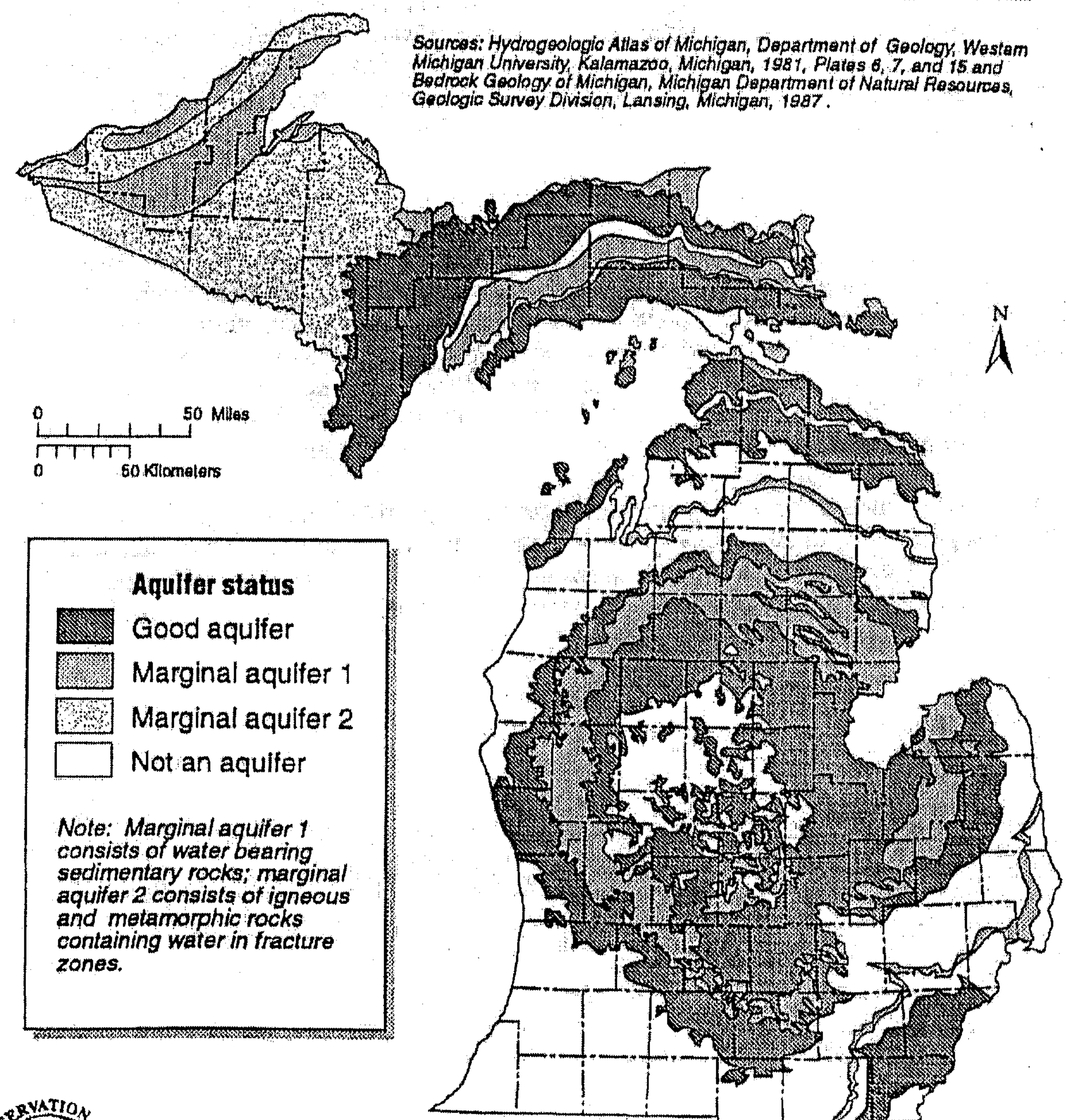
Most of the sedimentary rocks in the Michigan Basin originated as marine deposits. Near-shore areas in these ancient seas received sandy sediments which became sandstone when lithified. In somewhat deeper waters, fine-grained muds were deposited -- the source for our shales. In the deepest parts of these oceans, calcareous-rich sediments were deposited which through geologic time became limestone or dolostone. Special lagoonal environments under conditions of high evaporation rates account for the salt, anhydrite and gypsum deposits.

Most of the Ordovician, Silurian and Devonian Periods in Michigan's stratigraphic record are dominated by the carbonate rock types. Various grades of sandstone dominate much of the Cambrian Period and smaller portions of the Middle Ordovician, Late Silurian, Early Devonian, Early Mississippian and Late Pennsylvanian Epochs. Shales dominate much of the Mississippian Period and short intervals of the Late Ordovician, Early and Late Silurian, Late Devonian, and Early Pennsylvanian Epochs. The evaporites are confined largely to the Middle and Late Silurian and Middle Devonian Epochs.

Bedrock Aquifers

The availability of potable ground water in bedrock units is controlled, in part, by the porosity of the rock -- the ratio of the volume of openings in the rock to the total volume of the unit. We differentiate between two different types of voids in rocks. Primary porosity refers to openings that were formed at the same time as the rock. The pore spaces between the grains of sand in a sandstone are an example. If the voids were formed after the material was lithified, they are termed secondary porosity. Examples of these secondary openings are fractures in a crystalline rock or solution openings in a limestone. The hydraulic conductivity of a rock expresses its capacity to transmit water. The size and interconnections of the primary and secondary openings largely control this parameter. In Michigan, as elsewhere, the porosity and hydraulic conductivity of the different bedrock units vary considerably. Another factor to consider is that much of the saturated thickness of the bedrock in Michigan contains non-potable brine. Figure 22 illustrates the pattern and extent of the major bedrock aquifers of Michigan.

Bedrock Aquifers



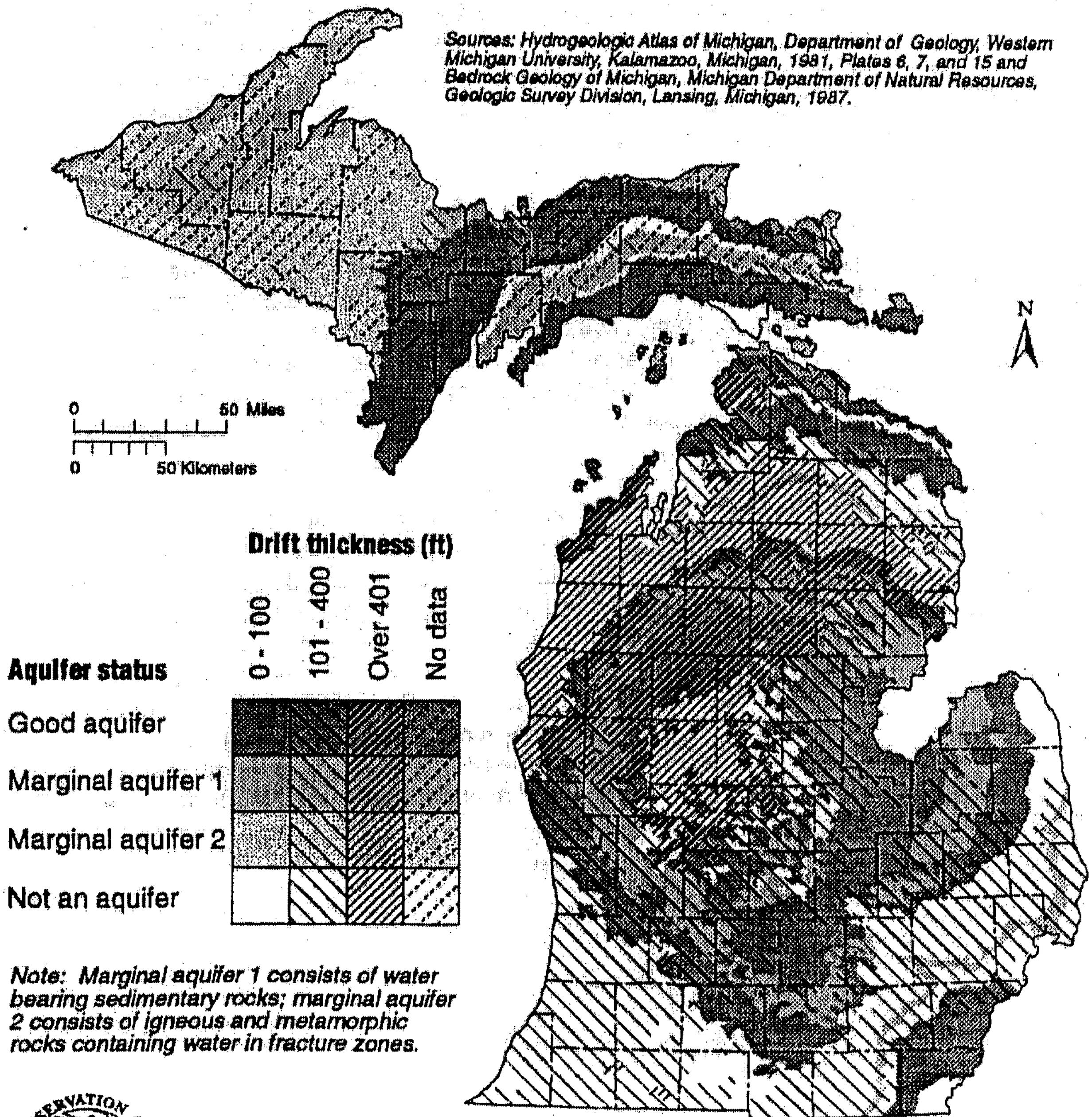
Agriculture's Role in Protecting Ground Water Figure - 22

Figure 23 shows the accessibility of the bedrock aquifers in terms of the thickness of the glacial materials which bury them in most places. The good aquifers shown on this map routinely provide potable ground water of adequate quantity and quality. The marginal aquifers are those which provide low-quality water and/or have highly variable transmissivities (i.e. notable changes in hydraulic conductivity and/or aquifer thickness from place to place). The marginal 1 class consists of saturated, sedimentary rock units. The marginal 2 class represents the igneous and metamorphic rock types in the western Upper Peninsula which have little or no primary porosity; in these hard rock areas, ground water is found only in joint and fracture zones.

Bedrock aquifers are frequently tapped for domestic water supplies in areas where they are overlain by relatively thin (0-100 feet) drift. Examples include the Keweenaw Lowland in the western Upper Peninsula, many areas of the eastern Upper Peninsula, the vicinity of Presque Isle County in the northeastern Lower Peninsula, the tip of Michigan's "thumb", the area around Monroe County in southeasternmost Michigan, and a swath of variable width extending southwestward from Saginaw Bay to the state line in Branch and Hillsdale counties. In contrast, the bedrock aquifers below the northwestern and north-central regions of the Lower Peninsula are typically buried beneath more than 400 feet of glacial drift and are, therefore, not generally accessible.

Many parts of the Lower Peninsula have little or no potable ground water in the underlying bedrock, making these locales dependent on drift aquifers or surface water supplies. The most notable of these areas are the entire southwestern region and a county-wide zone that traverses the southeastern sector of the state.

Accessibility of Bedrock Aquifers



Agriculture's Role in Protecting Ground Water — Figure - 23

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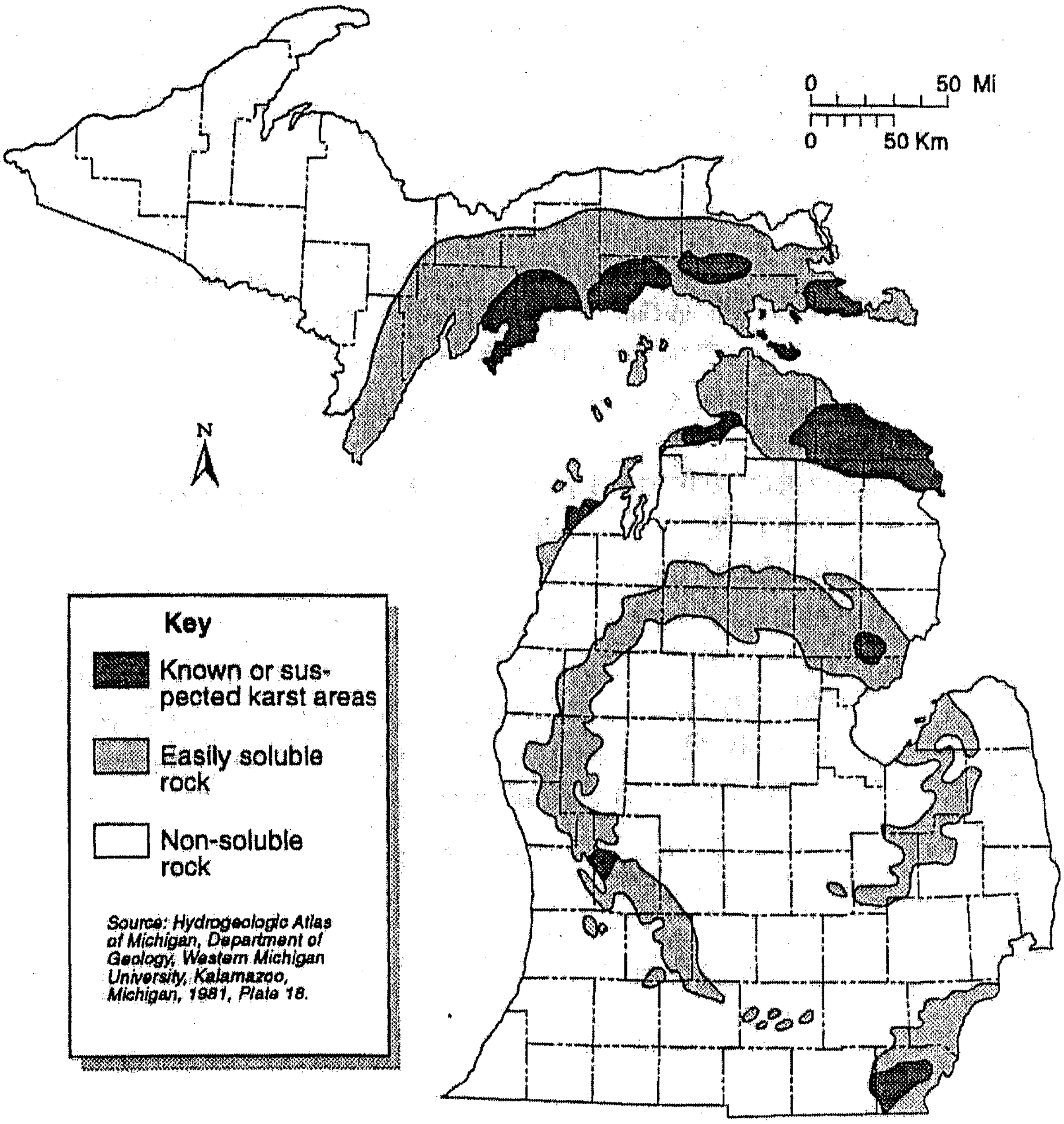
Areas of Special Concern

Within the Michigan Basin, there are numerous strata of carbonate rocks. These limestones and dolostones can be dissolved by water. In areas where the carbonate rocks are highly fractured, numerous solution-widened joints develop. These may extend underground for long distances. Progressive solution leads to the development of small cavities and larger caves and caverns. As subterranean solution continues, some of these solution features can collapse causing subsidence of the overburden. A landscape exhibiting these landforms is called karst terrain.

The various solution features associated with karst regions provide numerous pathways for surface contaminants to infiltrate very rapidly into the subsurface. The rates of ground-water flow in these systems can approach those of some surface streams. Even more disturbing, the subterranean interconnections between these solution voids are generally unknown and unpredictable. As a result, hazardous materials which move into the ground water in a karst region can travel very rapidly to wells located great distances from the contamination site. These conditions make the karst areas of Michigan particularly vulnerable to potential contamination from human activities at or near the surface.

The darkest pattern in Figure 24 depicts the known or suspected areas of karst in Michigan. The lighter-gray pattern delineates regions of easily soluble rock types where similar underground solution features are possible. In areas where these lithologies are near the surface, subterranean karst development is probable. Notably, the karst areas along the south shore of the Upper Peninsula, in the general vicinity of Presque Isle County in northeastern Lower Michigan, and in Monroe County in southeasternmost Michigan are all overlain by relatively thin amounts of drift -- usually less than 50 feet thick. Hence, there is minimal opportunity for the overburden to attenuate any percolating contaminants from the surface. Everyone who lives, works or recreates in these parts of the state needs to be especially conscious of and careful with hazardous substances.

Karst Areas in Michigan



Agriculture's Role in Protecting Ground Water

Figure - 24

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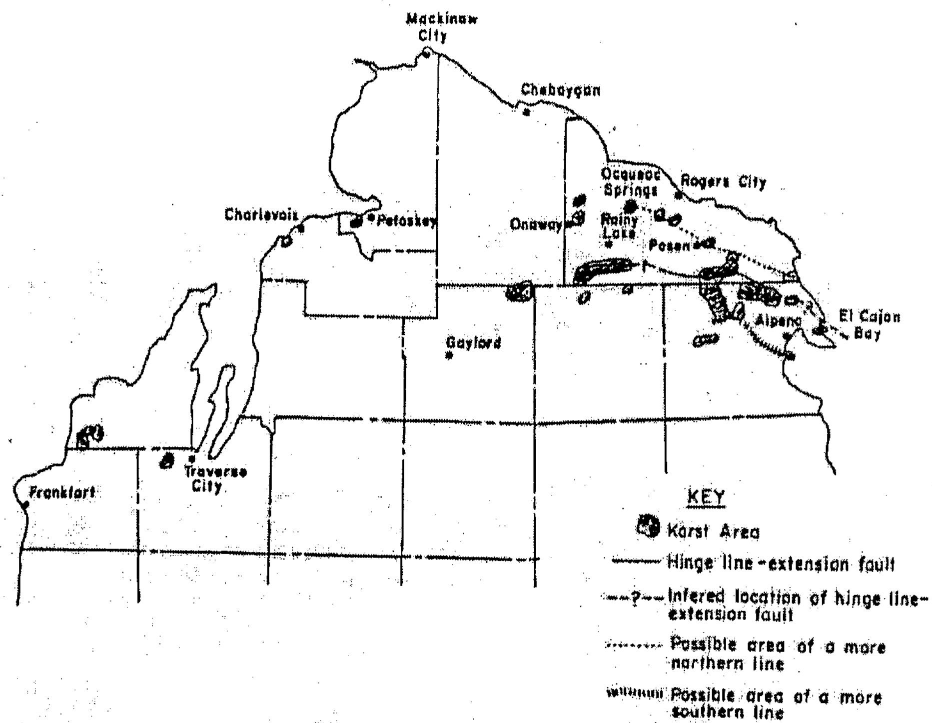
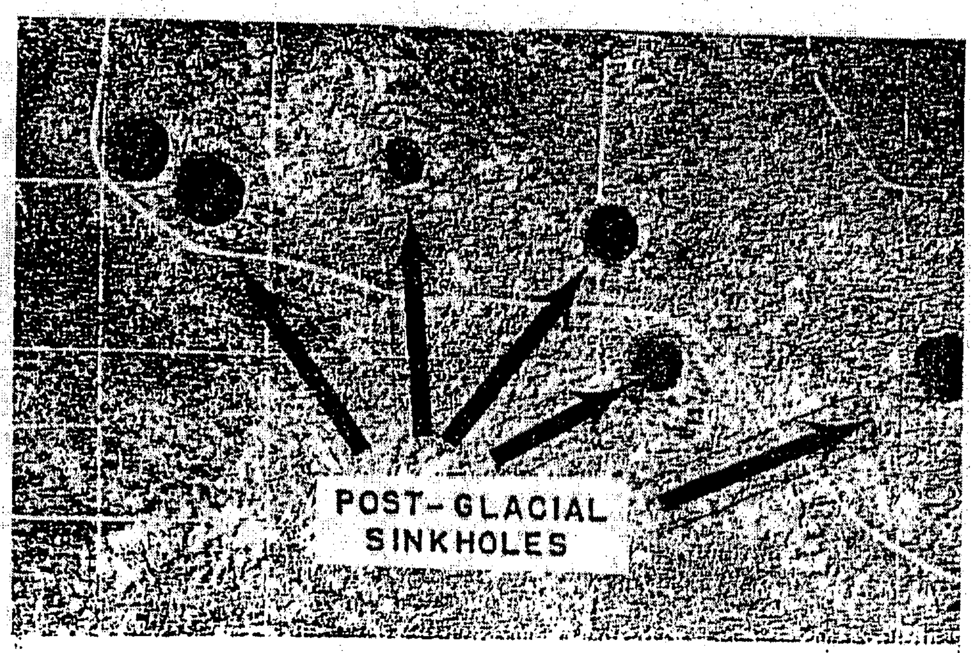
KARST

* TERRAIN WITH DISTINCTIVE HYDROLOGY AND LANDFORMS ARISING FROM A COMBINATION OF HIGH ROCK SOLUBILITY AND WELL-DEVELOPED SECONDARY POROSITY

* Karst is the German form of the Slovene word Kras which means "crag or stony ground" especially the bare rock surfaces of northern and coastal Yugoslavia.

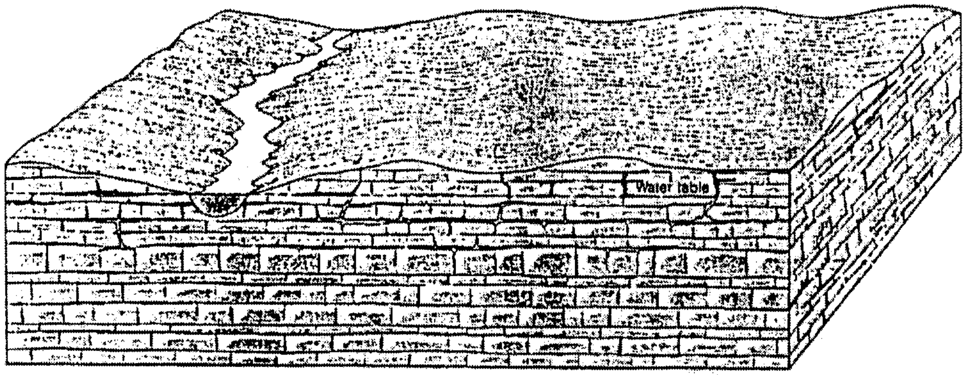
* The best-formed karst occurs in limestone and to a lesser degree in dolostone terranes, but it also forms in regions underlain by gypsum or rock salt. Although gypsum ($CaSO_4$) and rock salt (halite, NaCl) are more soluble than limestone, they occur much less frequently than limestone and then only in areas of limited areal extent



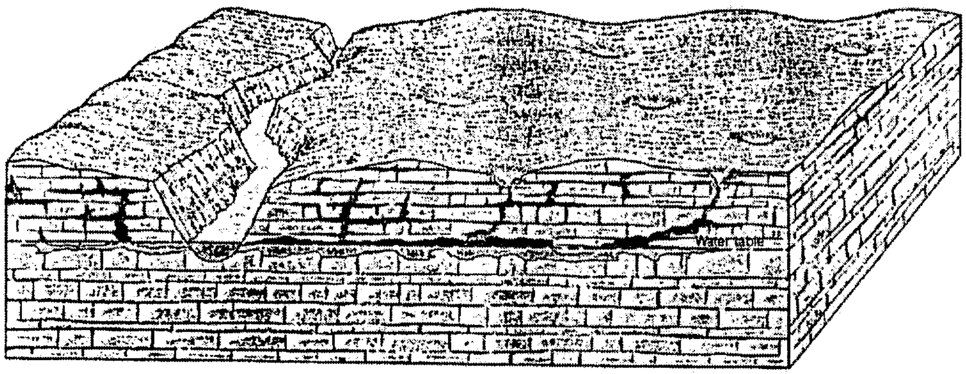


POST-GLACIAL SOLUTION FEATURES IN 30 TO 80 FEET OF DRIFT

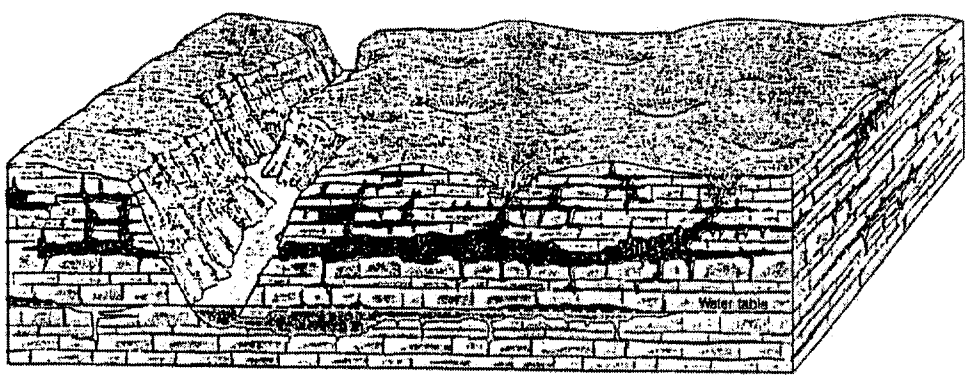
Prepared by David P. Lusch, PhD * Center For Remote Sensing * Michigan State University



(A) In the early stages, water seeps through the fractures and bedding planes of limestone formations. It seeps downward to the water table and then moves toward the surface streams.

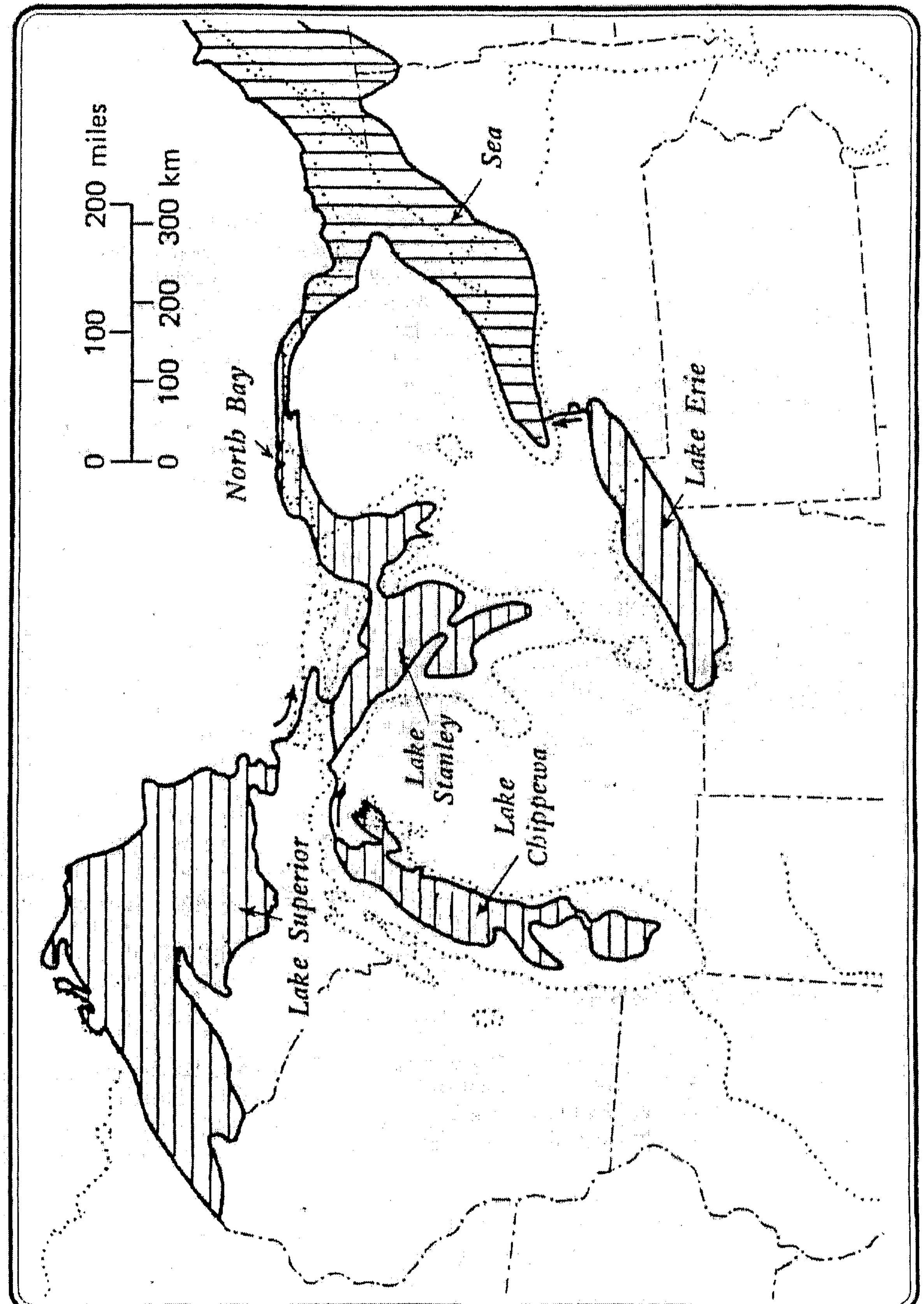


(B) As the surface streams erode the valley floor, the water table drops. The surface water seeping through the zone of aeration enlarges the existing joints and caves. Movement of water toward the surface stream develops a main system of horizontal caverns.



(C) As the river erodes a deeper valley, the water in the main underground channel seeks a new path to the lower river level. A new, lower system of horizontal caverns develops. The higher, older caverns may continue to enlarge and ultimately collapse to form sinkholes, or they may be filled with fallen rubble or cave deposits.

Figure 13.11
The evolution of a cave system is shown schematically in these diagrams.



Prepared by **David P. Lusch, PhD * Center For Remote Sensing * Michigan State University**

Glacial Geology

Introduction

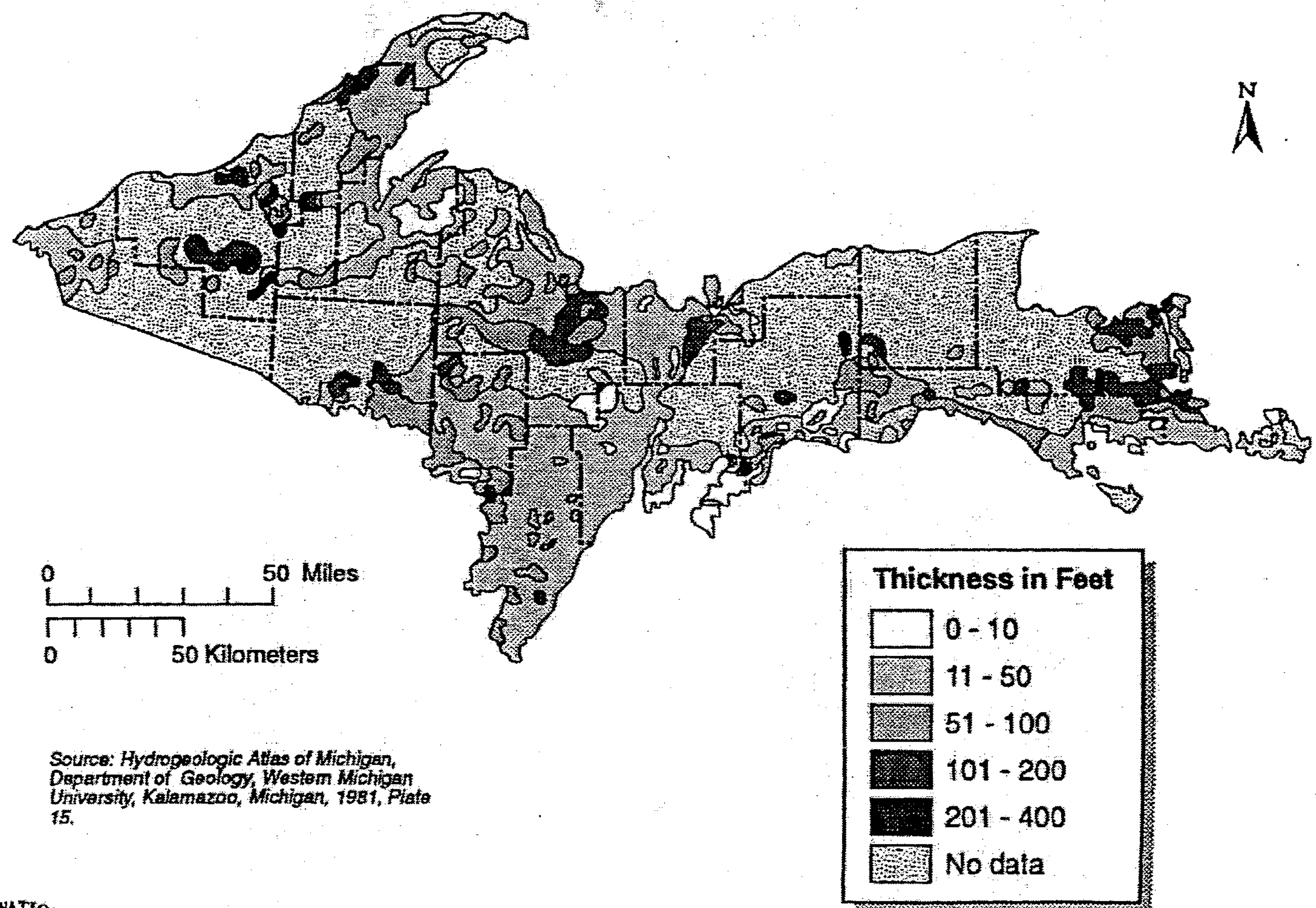
During the last ice age, all of Michigan and the bordering Great Lakes basins were engulfed by the Laurentide ice sheet. This continental glacier advanced into an area that had been glaciated at least three times previously in the recent geologic past. The initial invasion of Pleistocene glaciers probably encountered a rolling countryside that had been maturely dissected by flowing streams. This landscape was underlain by nearly horizontal sedimentary rock layers which possess varying resistances to erosion. The downcutting of streams is more successful in the weaker rock units and less successful in the more resistant strata. As a result of this differential erosion, geomorphologists envision that the pre-glacial Great Lakes Region contained several master streams which flowed, primarily to the east and north, across the terrain now occupied by the lake basins.

The advancing ice was capable of enhanced flow in these pre-existing valleys compared to the interfluves. As a result, the ice front was dissected into a number of individual lobes with adjoining interlobate areas. Each of the lobes followed the local path of least resistance. The Superior Lobe flowed southwest in the western Lake Superior basin past Duluth. The Chippewa Lobe moved southwestward out of Keweenaw Bay across the lowland between the Keweenaw-Ontonagon ridges on the west and the Huron Mountains on the east. The Green Bay Lobe, which advanced toward the south-southwest, was separated from the neighboring Michigan Lobe by the resistant backbone of Wisconsin's Door Peninsula. The Michigan Lobe, the most robust of the seven discussed here, expanded primarily to the south. The Huron Lobe, flowing southeastward and then southward, was separated from the Saginaw Lobe by the low, resistant bedrock cuesta that forms the axis of Michigan's thumb. Entering the state from the east-northeast, the Erie Lobe merged with the Huron Lobe in the vicinity of Detroit and advanced as far as southeastern Branch County.

Drift Types and Thicknesses

The glaciers left most of Michigan buried in a variety of unconsolidated materials -- clay, silt, sand, gravel, and mixtures -- which collectively are called drift. The thickness of the drift varies considerably across the state and is a principal factor in the economical availability of ground water in bedrock aquifers. Also, the thicker the glacial materials are, the more likely it is that multiple drift aquifers will occur at depth. Figure 25 depicts the drift thicknesses in the Upper Peninsula. Large areas of "no data" are shown due to the small number of water wells in this part of Michigan. Where data are available, drift thicknesses less than 100 feet are common.

Drift Thickness in Upper Michigan



Source: Hydrogeologic Atlas of Michigan, Department of Geology, Western Michigan University, Kalamazoo, Michigan, 1981, Plate 15.

Agriculture's Role in Protecting Ground Water

Figure - 25

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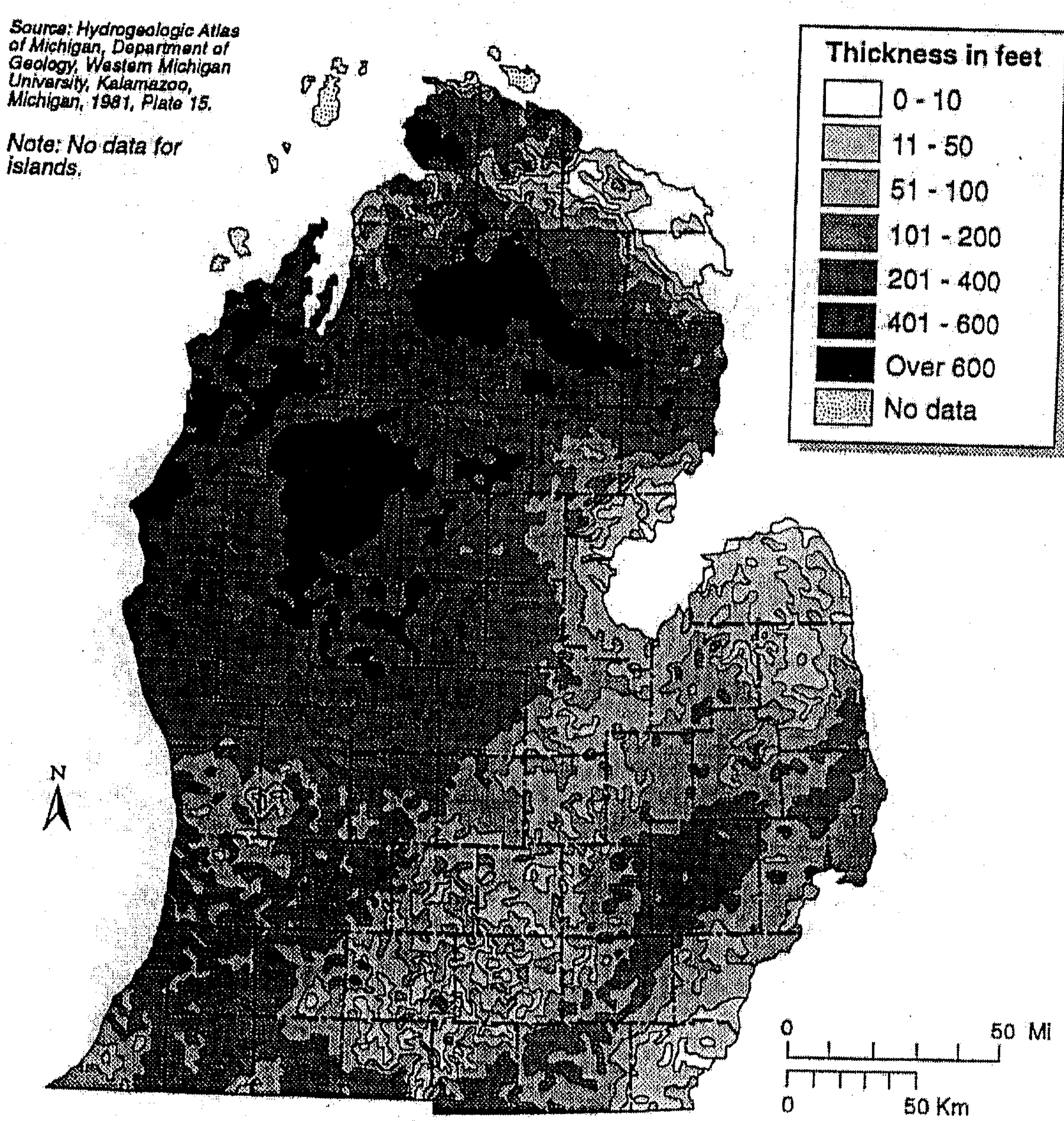
The picture is very different in the Lower Peninsula (Figure 26). Here, many parts of the northern half of the peninsula are deeply buried beneath 400 to 600 feet of drift. Many townships in Wexford, Osceola, and Otsego counties exhibit drift thicknesses in excess of 800 feet. This is in marked contrast to the very thin (less than ten feet!) drift in Presque Isle and Alpena counties. In the southern half of the Lower Peninsula, the drift is generally less than 400 feet thick. In this part of the state, the drift is thickest (200-400 feet) in the interlobate regions which trend from Cass County to northern Kent County in the southwest and, in the southeast, from Hillsdale County to southern Lapeer County. The tip of the thumb in Huron County, as well as most of Monroe County in the southeastern corner of the state, exhibit drift thicknesses of 50 feet or less. A two-county-wide zone of somewhat thin but variable drift thickness (generally less than 100 feet thick) trends southwestward from Saginaw Bay to Branch County.

Drift Aquifers

On a statewide basis, ground water in drift aquifers is a plentiful resource as indicated by Figure 27. Most of the state is covered with glacial deposits which store and transmit ground water in amounts and rates that could meet the requirements of a small domestic supply system. Of course, this is a great generalization and on a local basis drift aquifers may be rare. The light-toned areas on Figure 27 depict regions of the state where one or more of the glacial Great Lakes inundated the present upland surface and deposited clay-rich materials. These lake plains are low-relief surfaces underlain by dominantly fine-textured drift which exhibits very low hydraulic conductivities. As a result, drift wells are not routinely possible in these sections of the state. The dark-tone pattern on Figure 27 reveals the distribution of areas underlain by 30 feet or less of glacial deposits. The well construction code in Michigan specifies that all water supply wells must be cased to a depth of 25 feet. Considering the need for several feet of screen at the bottom of a well in unconsolidated material, these thin-drift regions of the state provide very little opportunity to develop wells which could meet this construction standard.

Drift Thickness for Lower Michigan



Agriculture's Role in Protecting Ground Water

Figure - 26

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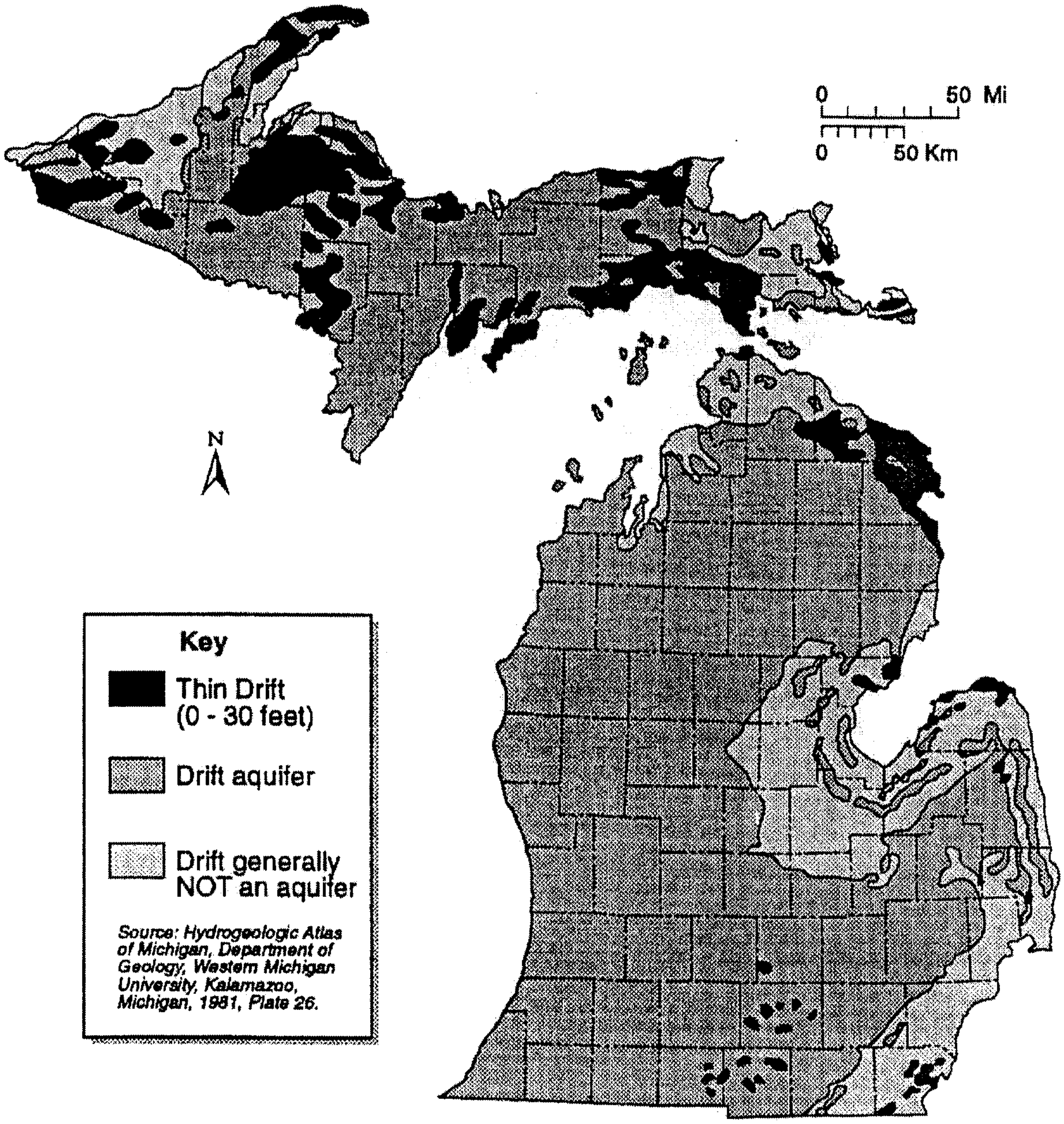
Drift Aquifers in Michigan



Agriculture's Role in Protecting Ground Water

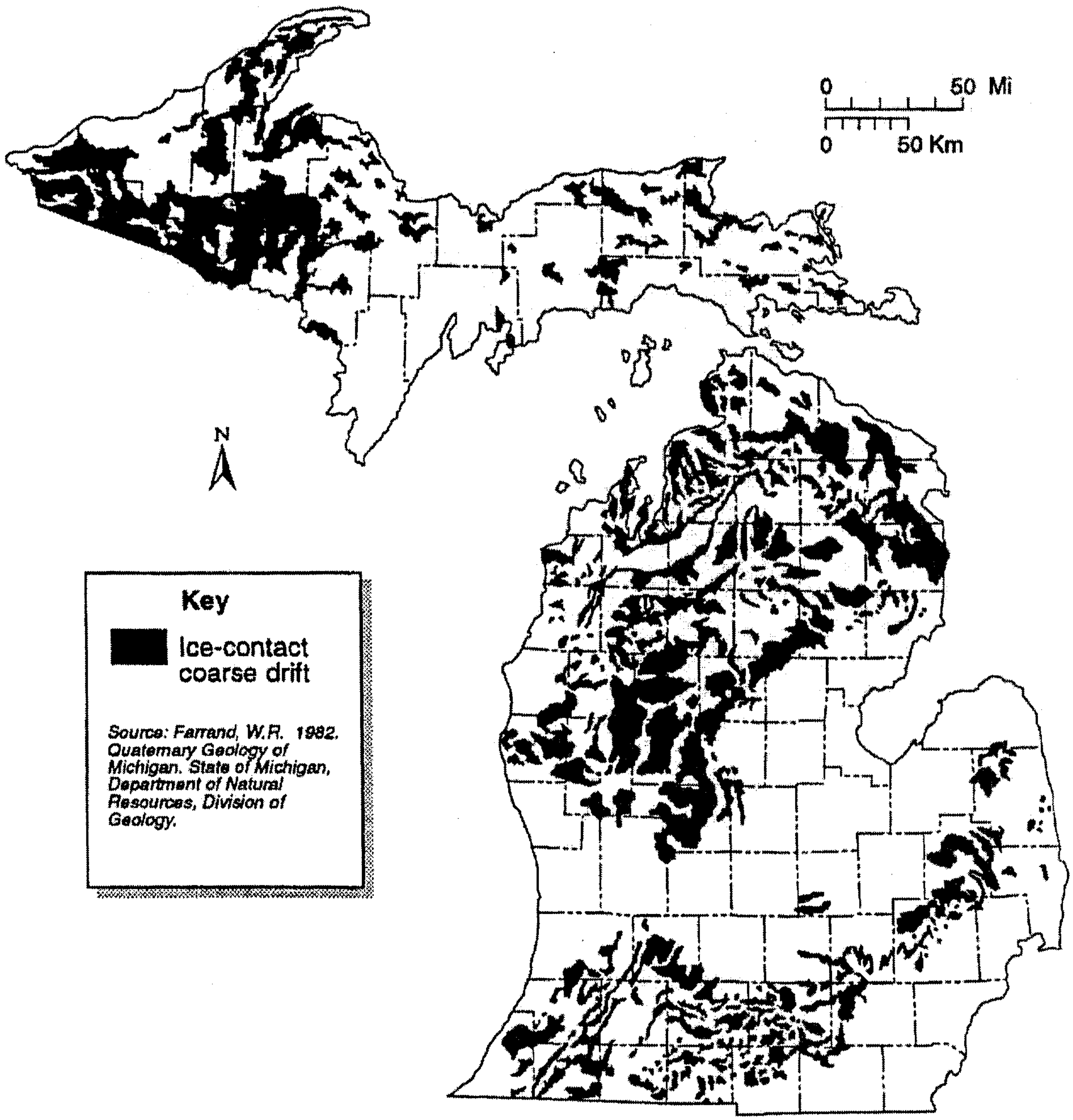
Figure - 27

Areas of Special Concern

We have seen that most of Michigan is covered with glacial deposits. From a statewide perspective, bedrock exposed at the surface is relatively rare. This implies that the water table (the upper surface of the ground water) is most often found in the drift. The vulnerability of ground water to contamination from the surface or near surface (i.e. human activities) is controlled primarily by the hydraulic conductivity of the materials through which infiltration occurs and the thickness of the unsaturated zone. Highly permeable soils allow surface contaminants to migrate rapidly into the subsurface. Less porous soils, on the other hand, inhibit the infiltration of contaminants. The depth to the water table (i.e. the thickness of the unsaturated zone) is a measure of the vertical distance that contaminants must travel in order to reach ground water. The elevation of the water table is a function of surface topography and the altitude of the local ground-water discharge zones. In general, the configuration of the water table mimics the form of the surface, but with much less local relief. For certain types of chemicals, the amount of organic matter in the soil modulates how effectively it can attenuate the potential contaminant.

Considering these factors, the ice-contact, coarse-drift terrains, shown in Figure 28, are some of the most vulnerable landscapes in Michigan. They are composed of highly porous soils which contain relatively little organic matter. Compared to proglacial outwash formations which are also composed of coarse material, the ice-contact landforms present a much higher degree of subsurface heterogeneity. They are typically underlain by a complex interfingering of varying textures which makes the ground-water flow regime very complicated. This combination of inherent vulnerability coupled with subsurface, three-dimensional complexity produces landscapes which are particularly challenging in terms of ground-water protection strategies.

Ice-Contact Coarse Drift



Agriculture's Role in Protecting Ground Water **Figure - 28**

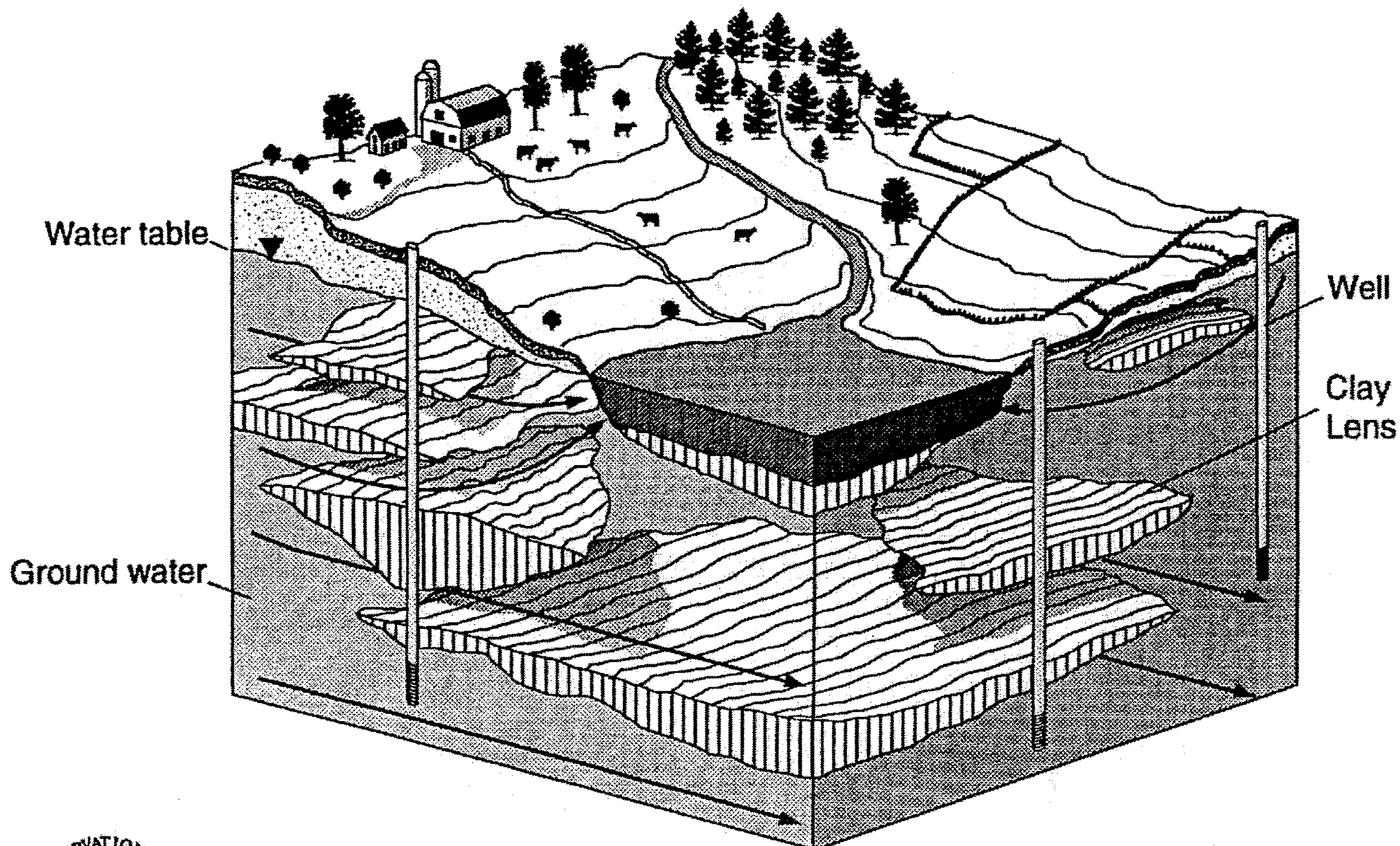
Naturally "Protected" Drift Aquifers

It is a well known fact that fine-textured earth materials transmit water very slowly compared to coarse soils. In Michigan, this concept is codified in the Rules of the Solid Waste Management Act (Act 641, P.A. 1978, as amended). As a means of safeguarding ground-water quality, these rules specify that a Type II sanitary landfill on a natural soil site should optimally be underlain by materials having a hydraulic conductivity no greater than 10^{-7} cm/sec. If the soil is thick enough, a hydraulic conductivity up to 10^{-6} cm/sec may be sufficient. These very low hydraulic conductivities are associated with clay soils.

Lakes and other still-water bodies are the environments in which clays can be deposited. Most lakes in Michigan are kettle lakes -- they occupy depressions which were formed when blocks of glacier ice finally melted after being partly or wholly covered by outwash sediments. Although some of these kettle depressions are very large, most are relatively small in size. In addition, since the littoral zone near the shore of a lake is the depositional site of coarse-textured material, it is only in the central portions of the lake that conditions are right for the deposition of clay. These facts suggest that most clay deposits will be local rather than regional in size. An inspection of the soil surveys of counties where clay-rich parent materials occur in abundance bears this conclusion out. Most soil map units that represent clay materials are 300 acres or less in size. Some larger areas of clay, up to 2,000 or 3,000 acres, do occur, but these are rare.

As depicted in Figure 29, the most common occurrence of clay materials in the drift of Michigan will be as discontinuous masses of relatively local extent, usually much less than 640 acres. As a result, the common assumption that extensive layers of clayey drift exist and provide natural protection to the confined aquifers at depth is largely incorrect. The infiltration pathway in the local area on the front left of Figure 29 is much slower than the pathway on the far right. However, recharge water (and any contaminants it carries) will infiltrate to the ground water system everywhere in the diagram. From this perspective, what some would call protection is really only an impediment to contaminant movement, not a barrier.

Discontinuous Confining Layers



Agriculture's Role in Protecting Ground Water

Figure - 29

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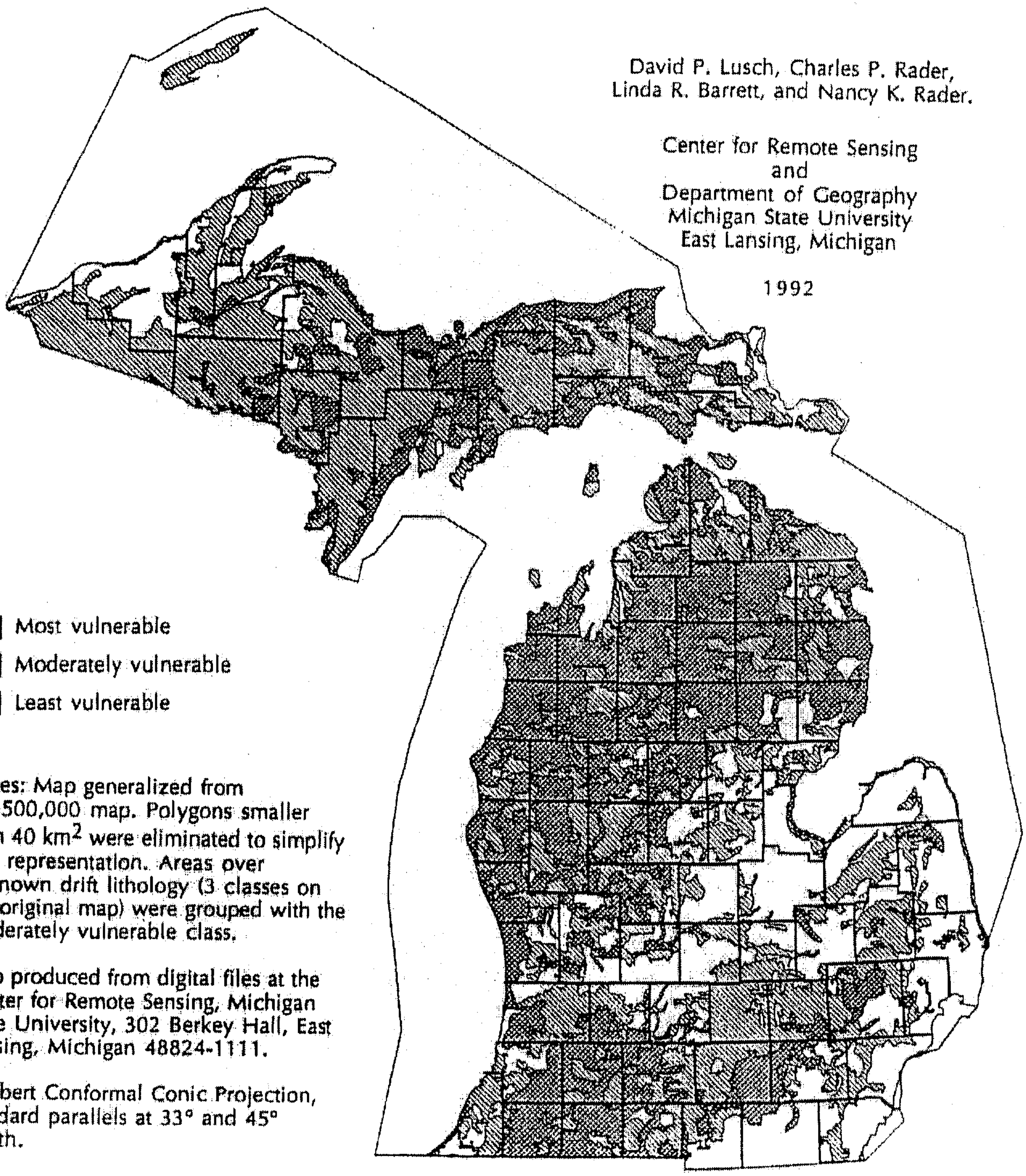
Aquifer Vulnerability to Surface Contamination in Michigan

David P. Lusch, Charles P. Rader,
Linda R. Barrett, and Nancy K. Rader.

Center for Remote Sensing
and
Department of Geography
Michigan State University
East Lansing, Michigan

1992



- Most vulnerable
- Moderately vulnerable
- Least vulnerable

Notes: Map generalized from 1:1,500,000 map. Polygons smaller than 40 km^2 were eliminated to simplify this representation. Areas over unknown drift lithology (3 classes on the original map) were grouped with the moderately vulnerable class.

Map produced from digital files at the Center for Remote Sensing, Michigan State University, 302 Berkey Hall, East Lansing, Michigan 48824-1111.

Lambert Conformal Conic Projection, standard parallels at 33° and 45° North.